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TEN YEARS OF WELDING DEVELOPMENT.

BY NORMAN L. MOCHEL.*

The author contributes in this article a retrospect of the last ten years of welding development. He points out the amazing hold which the art has won in all industrial applications, and illustrates the diversity of these with photographs of actual examples brought to perfection by his own Company. While he restricts himself almost entirely to an examination of the increased use of welding in marine engineering construction, his comments on technique and material as experience has been gained, are applicable throughout the many fields of its usefulness. His intimate association with this development, on the technical committees which have studied the subject, and through the practical applications which he has supervised for one of the largest manufacturing companies in the country, qualify him to speak with authority.

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Welding as a means for the joining of metal parts and as a repair measure has been known and practiced industrially for many years. There are numerous welding processes in use. In Figure 1 is reproduced a classification of the principal processes, as arranged by Llewellyn [1] in 1931. Some newer methods have been proposed and used, but in general the commercial methods in use today fall within a reasonable interpretation of this classification.

Progress in welding development has been quite rapid during the past ten years; indeed, in some fields of application, progress has been quite amazing in a very few years. This moving forward has not been limited to any one or even a few of the welding processes. Improved equipment and a better understanding of the fundamentals involved have resulted in general progress.

These few years have seen a widespread adoption of welding in important engineering construction, often in the place of older and well-established methods of manufacture. The very nature of some of the applications indicates the rapidity with which we have become welding-minded.

It appears quite unnecessary to the writer, in order to accomplish the real purpose of this article, to draw a hard and fast line through January, 1927, and attempt to show how poor we were, or how minor our efforts were, before that date. Some excellent welding, especially with the oxy-acetylene flame, and with the arc as well, was carried out in those days. The literature on welding records the experiences and names of those who labored, and many are the untold experiences and unrecorded pioneers of the period; we should recognize the important part they played in making possible the remarkable developments of the past decade.

The mention of a very few incidents, all taking place within the ten years, indicates the nature and extent of the developments. Probably no single incident is more important than that in 1928 the Boiler Code Committee of the American Society for Mechanical Engineers so recognized the development of the welding art as to consider tentative rules for the fusion welding of boilers and other pressure vessels. These rules later became standards, and have probably had more to do with the development of high-grade welding than any other single influence. They have been the basis

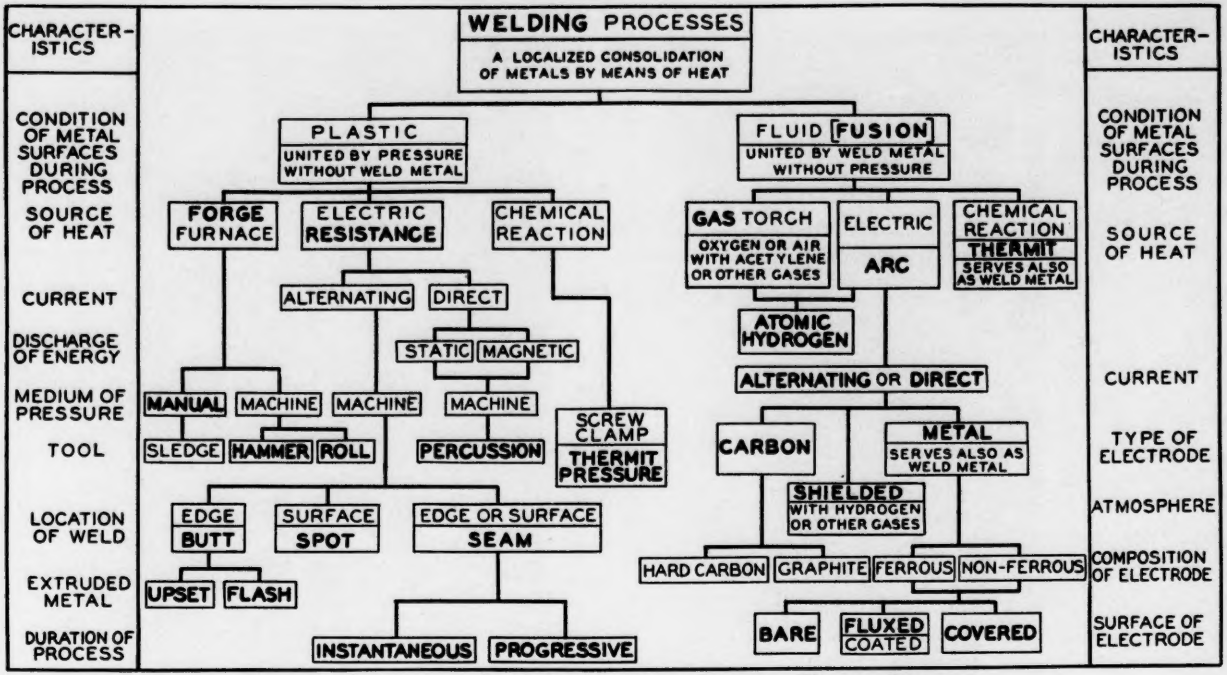

FIGURE 1.—SHOWING THE CLASSIFICATION OF THE PRINCIPAL WELDING PROCESSES.

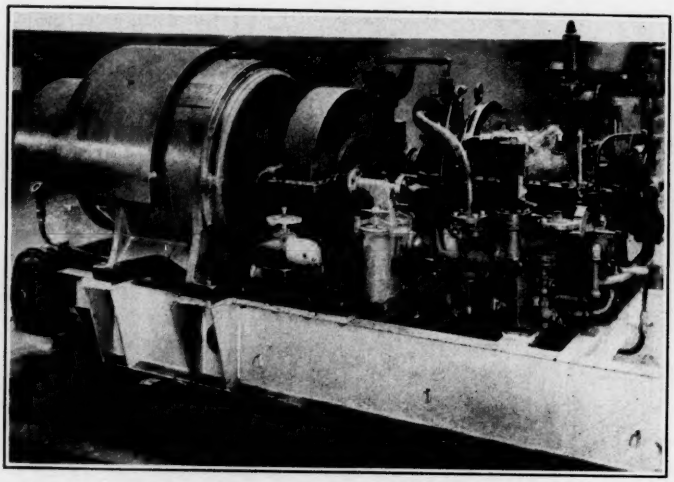

FIGURE 2.—MARINE TURBINE GENERATING UNIT.

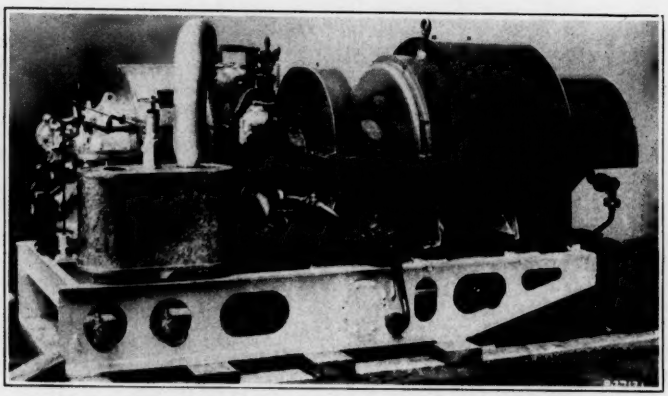

FIGURE 3.—MARINE TURBINE GENERATING UNIT.

for the formulation of many other codes and specifications, now in use in many fields of application.

In 1931 the American Society for Testing Materials recognized the importance of the advances being made by welding, and held a Symposium on Welding, that matters of materials, quality and testing methods might be openly discussed.

We have seen, rather than heard, the construction of new buildings, many of goodly size. A girder practically 100 feet long and 7 feet deep is being constructed entirely by welding for a large building. Some of these all-welded buildings have been in service for the greater part of the decade. Their reliability is no longer in doubt.

We have seen railway and highway bridges constructed and altered by welding. In 1934 the American Welding Society appointed a committee to prepare a " Specification for the Design, Construction, Alteration and Repair of Highway and Railroad Bridges by Fusion Welding." The specification was completed and adopted this year.

The petroleum industry has made quite extensive use of welded construction. In 1934 it adopted a Code for Unfired Pressure Vessels, in which welding is recognized as an acceptable method of construction.

State codes intended for the protection of lives and property have been revised to include rules for welding. Insurance companies now insure welded plant and equipment. Welded " Zephyrs " speed along our railroads, welded automobiles on our highways, and welded airplanes drone through our skies.

The enormous gate valves and penstock piping at Boulder Dam are of welded construction. The Milwaukee Sewage Disposal Plant used tons of stainless-clad plate joined by welding. A 200-inch telescope is being constructed of welded members.

Foundries have closed their doors, and moulders have sought and some have succeeded, to become welders. Small " necessary-evil " welding departments have grown to plant size. Steel plate divisions of our producing interests have enjoyed increased production.

Equally important and equally amazing developments have taken place afloat, as on land. And again, the very nature of some of

these indicate the rapidity with which welding has been adopted in recent years. For a time grave fears were expressed that probably in no other industry would arc welding meet with such opposition as in the shipbuilding industry. But what has actually taken place?

A new type of battleship appears abroad, with all-welded hull construction. Hulls for tankers and other merchant vessels are being welded. Welded steel barges are propelled and towed on our inland waterways.

The "Morning Post" of London informs its readers that welding has been developed enormously in America in the past few years, and it discusses the extent to which welding is replacing rivets in new cruiser construction in the United States, also the utilization of welding in gun mountings.

The same paper reveals the alleged plans of the New York Yacht Club to defend the America's Cup against *Endeavor II*, by the construction of a new all-steel welded hull, to accommodate *Rainbow's* gear.

The Navy, the Bureau of Steamboat Inspection, the American Bureau of Shipping and Lloyds Register of Shipping have all revised their rules and specifications to include requirements for welding and welded construction.

The gargoyle-like bow and receding hull of a cruiser in dry dock fills the cover of a well-known industrial publication devoted to welding, with the explanatory comment that "there is no larger user of welding than our own Navy. From keel to topmast, welded fabrication is much in evidence. The United States Naval Engineers have contributed much to the progress that welding has made in recent years."

We have touched just a few high spots and their effects in this very hasty and rambling look around. But the extreme variety of these few examples, the great size of some of them, and the thousands of other examples that could be given, clearly show the position that has been taken by welding in the field of engineering construction. The situation is a tribute to the coordinated efforts of chemist, metallurgist, and engineer, to the intelligence of the designer, the skill of the workman, and to the courage and conviction of the engineer and executive.

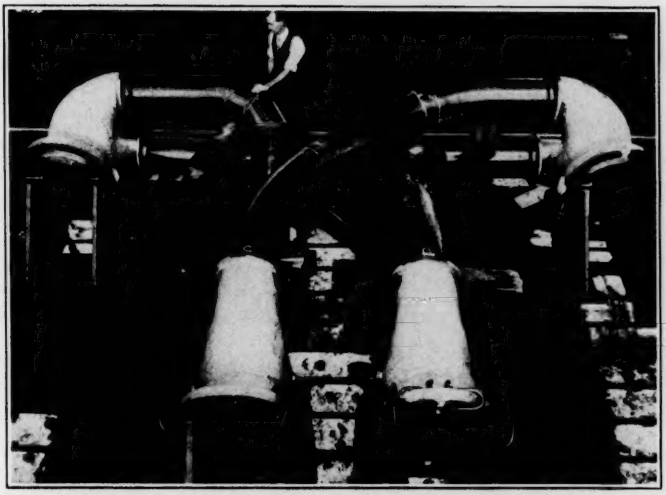

FIGURE 4.—WELDED STEAM PIPING, WITH ALLOY STEEL CASTINGS AND WROUGHT STEEL PIPE.

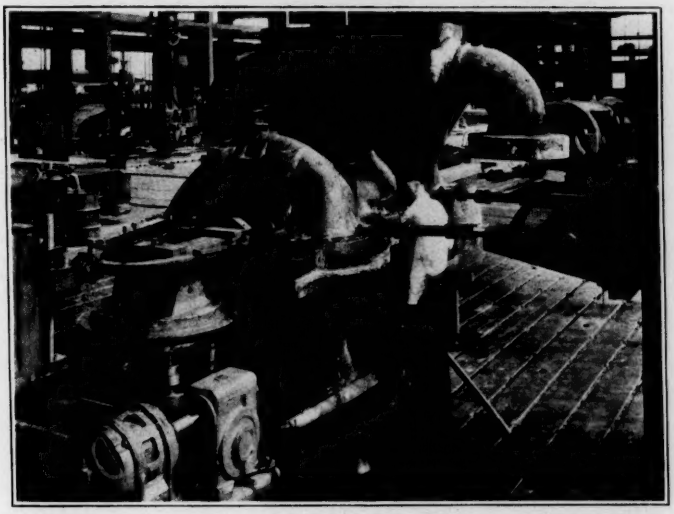

FIGURE 5.—H.P. TURBINE CYLINDER WITH WELDED STEAM INLET ELBOW.

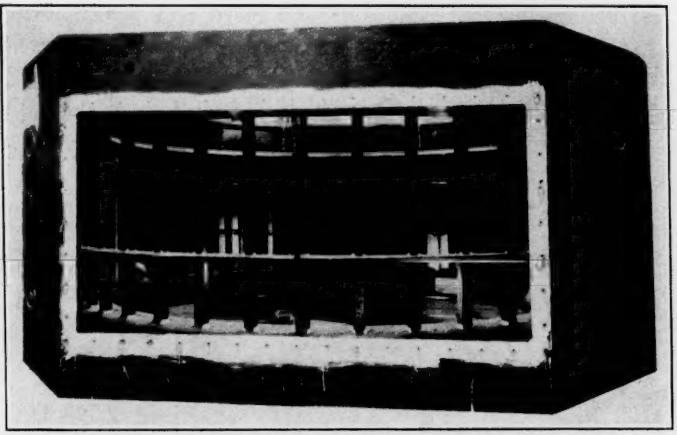

FIGURE 6.—WELDED FRAME FOR MAIN PROPULSION MOTOR.

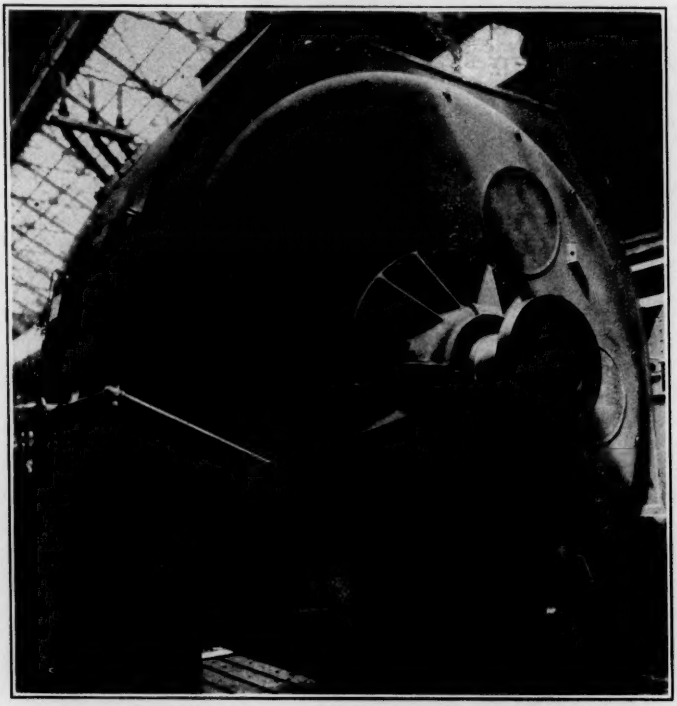

FIGURE 7.—PROPULSION MOTOR FOR ELECTRIC-DRIVE LINER.

It is the intent of this article to deal specifically with the development and application of welding in that particular field of engineering activity that supplies mechanical and electrical apparatus for use on board ship. If in so doing, the article deals almost entirely with the development of but one of the many welding processes, that is, the electric arc method of fusion welding, it is not that some of the others are not worthy of review, but that the developments in the particular field under consideration, have been largely through the growth of this method.

Developments in mechanical and electrical apparatus for land service invariably find their way, wholly or partially, into the marine fields, and vice versa. Indeed, during a goodly part of the ten-year period under consideration, many of the developments had their origin, or there was first the opportunity to gain practical experience, in marine applications rather than in those for land service.

In such a review as is attempted in this brief article there is probably greater value in pointing out trends, and reasons, and changing practice and ideas, and features of fundamental importance, rather than merely exhibiting the multitude of machines and fixtures that have been constructed by welding.

Let us first consider a number of features of quite fundamental importance in the progress made.

WELDING ELECTRODES.

At the beginning of the period, there were comparatively few types of electrodes from which to choose. Today, there are many. While the value of applying a flux or coating to electrode wire has been known for many years, and practiced in some measure by some before the beginning of our ten-year period, it is nevertheless true that the great bulk of welding ten years ago was done with bare wire or lightly coated wire. The swing to heavily-coated electrodes was first gradual and then more rapid, especially during the past four years. The following estimates by Muller [2] show the trend in the past three years:

	Total Welding Wire Used
1933	39,000,000 pounds
1934	57,000,000 pounds
1935	79,000,000 pounds

Grade or Type	*Percentage of Each Type*		
	1933	1934	1935
(*a*) Bare Wire	26.7	20.3	14.7
(*b*) Dust Coated	15.2	14.9	11.6
(*c*) Automatic (a and b types)	5.2	3.3	3.9
(*d*) Lightly Coated	14.2	7.8	6.2
(*e*) Heavily Coated	32.6	47.7	58.1
(*f*) Special Steels (carbon)	2.5	2.1	2.3
(*g*) Low Alloy Steels	3.4	3.2	2.5
(*h*) Stainless Steels	0.1	0.7	0.7

The development has now reached the point that when one refers to welding for nearly any application afloat, and especially for mechanical apparatus, he more or less automatically assumes the use of heavily-coated or "shielded arc" electrodes.

The various electrode manufacturers have been very busy during the entire decade. They have contributed immeasurably to the success of recent years. They are offering many types of electrodes, that the fabricator may select those that best suit his immediate purpose. The idea of a universal type of electrode is passing, and there is recognition of the fact that electrodes can be devised that will best meet some given condition of deposition. For example, fillet welding in a downhand or horizontal position is one of great importance. The greater part of the welding in many kinds of construction is of this type alone. It is only recently that it has been recognized that electrodes can be produced specifically for this purpose, which will speed production, give high grade welds, and work of superior appearance.

The development of electrodes for vertical and overhead welding has caused considerable concern. Herein is room for much improvement. There is still much distrust of welding that is per-

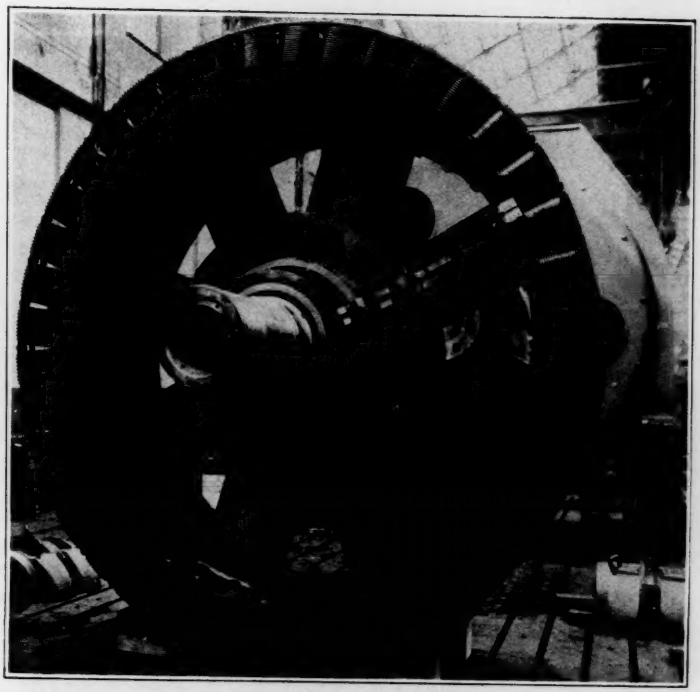

FIGURE 8.—ROTOR FOR MOTOR IN FIGURE 7.

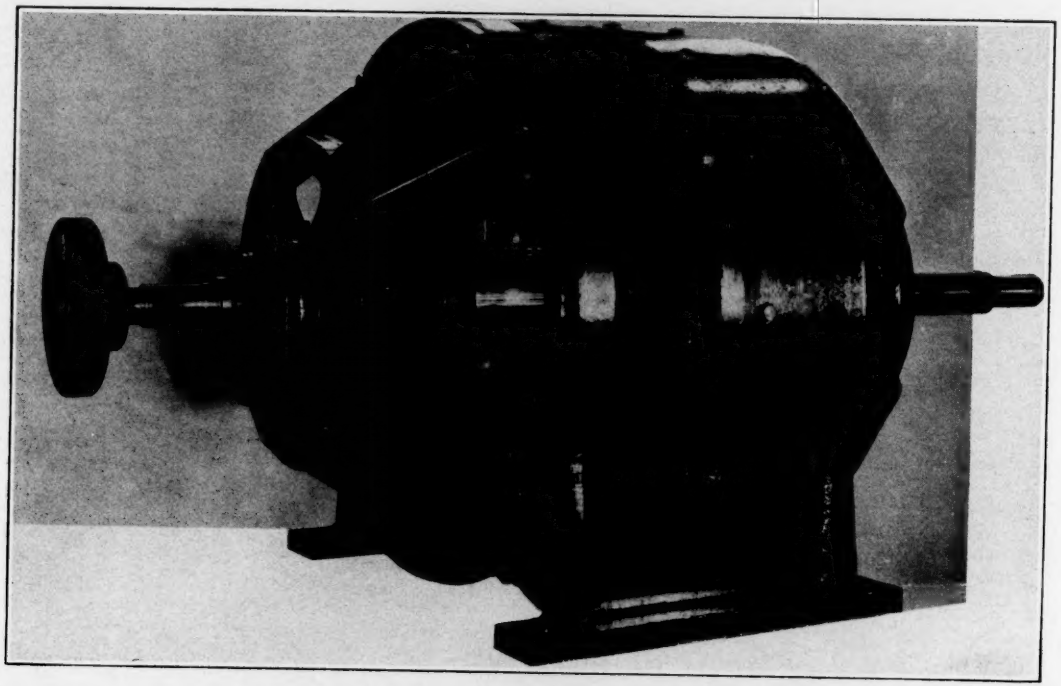

FIGURE 9.—TYPICAL MARINE MOTOR—150 H.P.

formed in these positions, and many discriminating purchasers require important welding to be performed in a flat or downhand position.

With the growing use of A.C. welding, a new problem has been introduced. All electrodes are not suitable for use with both D.C. and A.C. equipment, and again careful selection of the proper electrode for given conditions must be made.

Automatic welding with heavily-coated electrodes and electrode wire has been very successful in a number of places. This matter is receiving more and more attention, but there is much further development necessary before any general adoption.

There are still the two major types of heavily-coated electrodes, the "shielded-arc" electrode with cellulose coating and the "slag producing" electrode with mineral flux coating. There is still much secrecy surrounding the composition of coatings used, and a patent situation surrounding this feature that is quite complex. Despite the various reasons advanced by the two schools of thought, both types are giving sound and reliable welds; and more recently there has been a sort of merging of the two types, especially for specific purposes, with marked success.

There has been considerable difficulty in arriving at commercial and private standards for the purchase of electrodes and welding rods, and purchase is still largely upon the basis of trade or brand names. The Navy has made more progress in this matter, in the writer's opinion, than any other user. The measure of the ability of an electrode to produce a desired type of fillet is one example of progress along these lines. It is believed, however, that the great amount of thought being given the matter is one stage of progress.

In the matter of low-alloy steel electrodes, again there are two schools of approach. The one would make the electrode wire of the desired or corrected alloy composition. The other would introduce the alloy through the medium of the mineral coating, using a more or less standardized mild steel electrode wire. The latter appears to offer much in the way of flexibility and practicability to meet any given condition at hand.

With the growing understanding that welding involves steel or alloy making in miniature, and with the electrode manufacturers

extensively engaged in further improving their product, and with the very apparent desire on the part of some to better serve the fabricator along special lines, the further development of the welding art as a whole will be definitely advanced from this source.

MATERIALS FOR WELDING.

As fusion welding involves the actual melting of the material being welded, and the intermixing of the melted base metal and a portion at least of the deposited metal from the electrode, and as in addition there are important thermal effects in the adjoining metal, the general nature of the metal to be welded should be of fundamental importance. In a sense, however, this has been given very little consideration in actual practice in the great bulk of welding.

In many of the more important applications of steel and other materials, the ultimate purpose or method of use are carefully kept in mind from the selection of scrap to the finished product. Strictly speaking, there has been very little of this type of control in the making of base materials for welding. The rapidly growing welding art found many commercial and private specifications for materials already in existence, which appeared to offer material that should be suitable for welding. If one consults those lists of materials considered suitable for welding, as found in various codes and specifications, he will find that practically all of those listed are produced, or at least by title are intended, for purposes other than for arc welding. This is, in itself, highly complimentary to the welding art, since it did not require the development of new materials from the standpoint of weldability, but has had much of its amazing growth in the past ten years with what it could get in the way of base materials.

Some progress has been made in the suggested matter. For example, specifications for heavy plates for boilers and pressure vessels have included requirements and tests for laminations, which would affect welding and the welded product. Other specifications control the chemical composition beyond that normally practiced, even to many impurities. Others specifically mention that the material shall be suitable for arc welding, assuming the right to reject the material on this account should trouble develop.

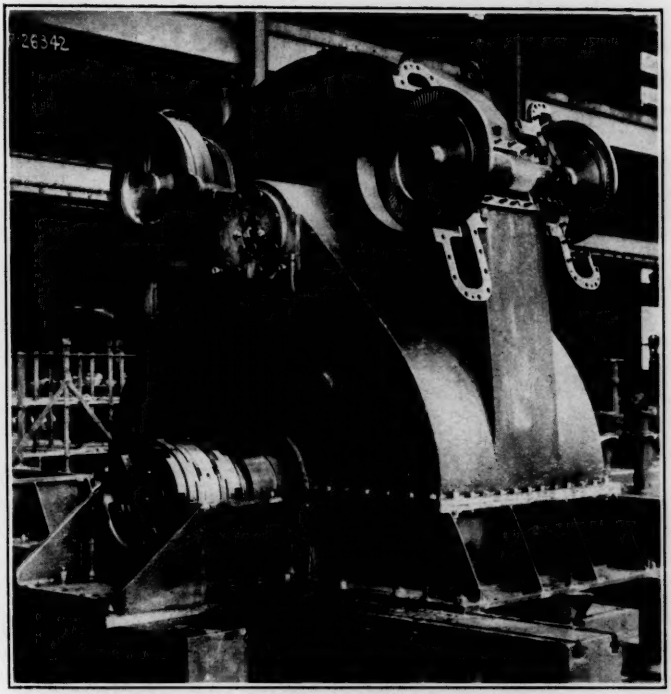

FIGURE 10.—1500 S.H.P. REDUCTION GEAR AND TURBINES.

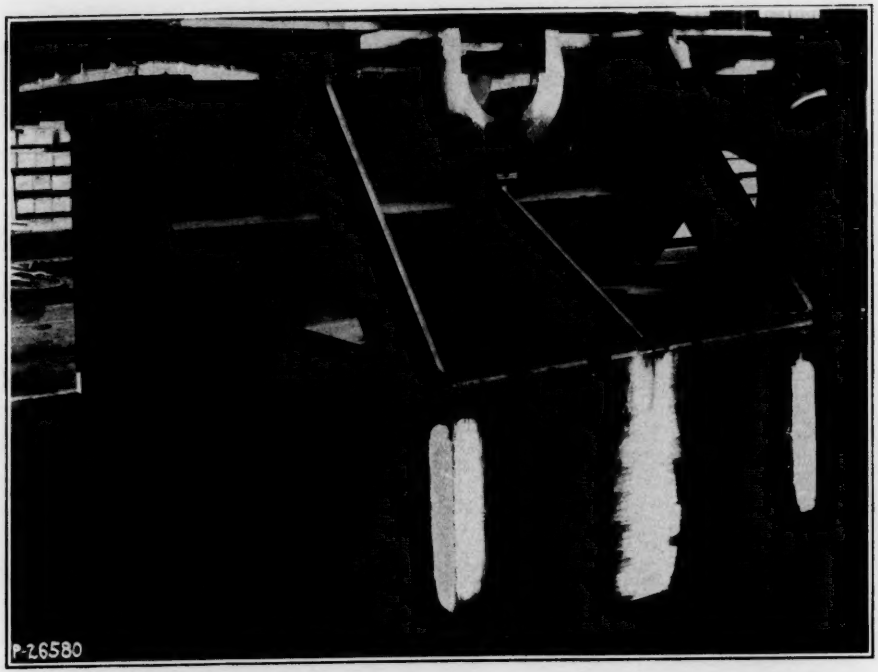

FIGURE 11.—3100 S.H.P. REDUCTION GEAR HOUSING BASE.

Other specifications contain footnotes suggesting that the purchaser and seller agree on changed composition and physical properties, if the specified material is to be welded, thereby indirectly advising that the specification itself be not used. There appears to be much reluctance in some fields where welding is being applied, and especially where alloy steels are involved, to standardize materials for the purpose. There is some feeling that such attempts might hinder progress in a rapidly developing art. There is much difficulty in standardizing weldable materials for many purposes.

There is much discussion today relative to the term " weldability." It cannot have a fixed meaning. To consider weldability, one must consider two things primarily. We must first consider the " yardstick " with which we would measure, and secondly we must consider the method or technique by which we will weld, and the limitations involved. Under the first, the results we would secure may be acceptable for one application and entirely unacceptable for another application. Under the second consideration, the nature of the parts to be welded, or the location of welding may place such restrictions on the technique of welding that acceptable results could not be secured, and the material would be considered non-weldable. However, the removal of such restrictions might easily change the conditions to entire acceptability. In the case of outside welding, the very season of the year, or variation of climatic conditions from day to day, may be all that is necessary to list the same material as weldable and non-weldable, for a given application. One may preheat in some cases, in others this cannot be done. One may finally heat treat or stress relieve in some cases, in others such is not possible.

There is something, however, of more fundamental consideration than those things already mentioned. Probably most fabricators, at one time or perhaps often, have experienced poor results, unsound welds, poor penetration, or other condition, that after checking and satisfying themselves that electrodes, operators, equipment, shop conditions, and all were right, came to the conclusion that the poor results were due to something in the base material. Sometimes the trouble with the base material can be determined with the means at the fabricator's disposal, more often the mystery remains unsolved. One cannot refrain from the thought that as

welding consumes a very healthy portion of the more common base materials produced, it is deserving of more attention than would appear to have been given by the manufacturers, to see if its diet cannot be improved upon from the standpoint of weldability. The technique of melting, the amount and nature of inclusions, the inherent grain structure, the amount and nature of occluded gases, conditions of internal stresses; these are but a few of the many lines of study. The development of materials especially intended for welding, and to meet given conditions of welding, would appear worthy of our future consideration.

A great variety of materials, both ferrous and nonferrous, are being successfully welded today, although many of these materials have rather limited application. Few, indeed, are the materials that someone does not want to try to weld. "Can it be welded?" is a question that any metallurgist, seeking to introduce a new or revised material, must be prepared to answer.

PERSONNEL MATTERS.

The matter of personnel is of great importance in our ten years of welding development, and is worthy of passing comment. The welder today is a far higher-type individual than he was ten years ago. It has been the writer's experience and observation that the welder takes a keener interest in his work and studies the problems beyond the mere laying-down of metal. We find some of the more progressive studying metallurgy and mechanical engineering at night, that they may take their practical experiences to other positions in the future.

Trade schools have sprung up here and there. Universities arrange periodic conferences on welding. The larger interested companies have established schools not only for training their own men, but to which other companies may send their men for training. Local chapters of the American Welding Society with their monthly meetings are educational for all those who are interested in any way.

Many concerns found it beneficial to assign engineers to the study of welding, to later direct the design of the welded product. Time and cost studies by those qualified to do so have materially assisted in a more understanding viewpoint of welding.

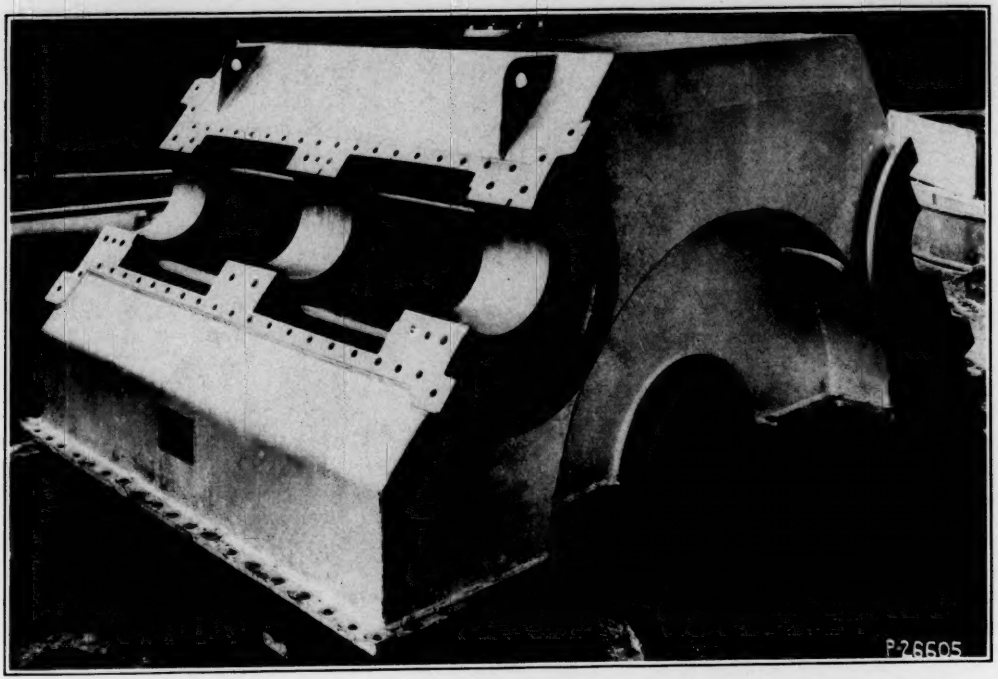

FIGURE 12.—COVER FOR LARGE MARINE GEAR CASING.

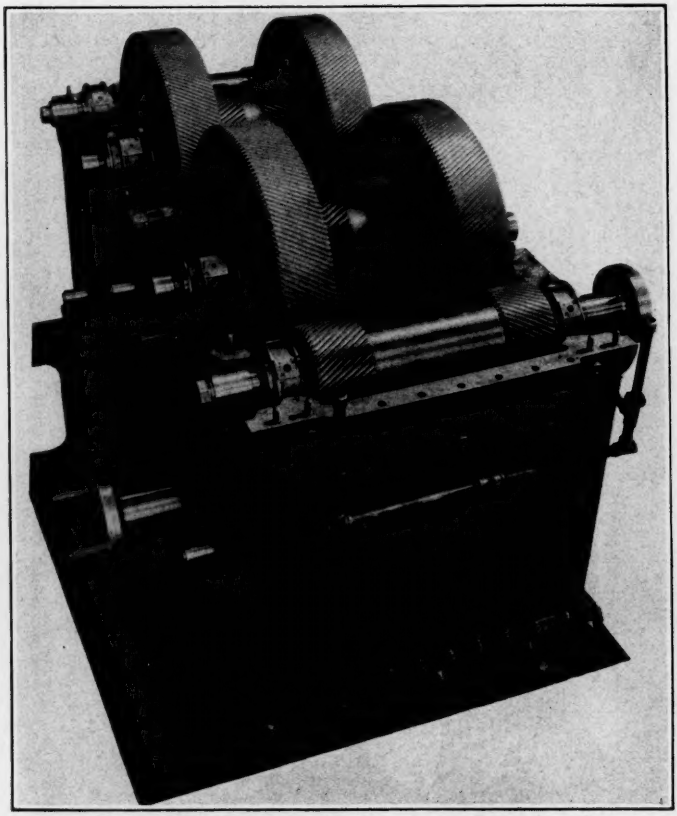

FIGURE 13.—3100 S.H.P. REDUCTION GEAR HOUSING WITH PINIONS AND GEARS IN PLACE.

Beginning with the application of welding to more important structures, various systems of certification or qualification of welders came into being. These have developed along many lines. At the present stage of the development of welding, one can find no good reason against such a practice, if honestly and carefully carried out.

However, each new governing body entering the field has been inclined to ask for some condition of test just a little more or a little different than those already in existence and this has added greatly to the complexity of matters. It is a very difficult and expensive matter to have welders qualified to meet the many codes and specifications that a fabricator may meet in his everyday existence. There is great need for standardization along these lines, and it is the writer's opinion that such could be accomplished without loss of reliability of workmanship.

There is also need for simplification. In some codes and specifications, it is difficult to clearly understand whether the tests are devised to test the material, or the electrode, or the man. The more recent requirements of the Navy Department are along the lines of simplification that are so much to be desired.

MATTERS OF TECHNIQUE OR PRACTICE.

The many problems that have been encountered in the development of welding during the past few years, arising from the very complicated designs, the immense size of some structures, the type of materials, the close dimensional tolerances and correctness of form required, and the stability imperative in service, have naturally required a rapidly changing and expanding technique or practice. Modern welding is a matter of careful planning, of adequate fixtures and supports, a proper sequence of actual welding.

There is a better understanding of the mechanism and of the value of proper stress relieving of welded structures. The use of such treatment during the welding operations, as well as a final operation, is recognized in many structures.

Of more recent development is the preheating of parts before welding, and maintaining a desired temperature during the welding, and immediately stress relieving following welding. Although practiced especially in the case of many alloy steels, such practice

may be used to advantage in welding mild carbon steels, in order to control shrinkage, or to minimize stresses, or to secure other required results.

These are but two examples out of many, illustrating advances in practice that have been made.

EQUIPMENT.

Of equal importance to matters of electrode development and personnel development, is the matter of equipment. The manufacturers of welding units have more than contributed to the present position of the art. There is much improvement in modern apparatus over that of just a few years ago.

INSPECTION METHODS.

At the beginning of the decade there was much uncertainty as to the soundness and reliability of welding for important applications. In the original official consideration of welding for boilers and other pressure vessels, it was felt that some form of nondestructive testing other than mere hydrostatic pressure tests was necessary. A number of methods were proposed. The ability of X-rays to penetrate opaque matter had been known for years, and the Watertown Arsenal had been examining steel casting by this means for several years, and this method of examination was readily adapted to the examination of important welded joints. The practice has spread rapidly from two installations in 1930 to about 40 in this country at the present time, that are used for the examination of the welded product.

For the examination of thicknesses beyond the capacity of existing X-ray apparatus, and for the examination of structures not readily adapted to the X-ray method, Gamma-ray examination with radium has been developed, largely through the work of the Navy in the examination of castings.

Several methods for examining welds by magnetic means have been proposed. The so-called "magnaflux" method is gaining favor, and is being used to advantage, often supplementing the radiographic examination.

These methods are, of course, additional to various physical tests, such as tension, impact and various bend tests, specific gravity,

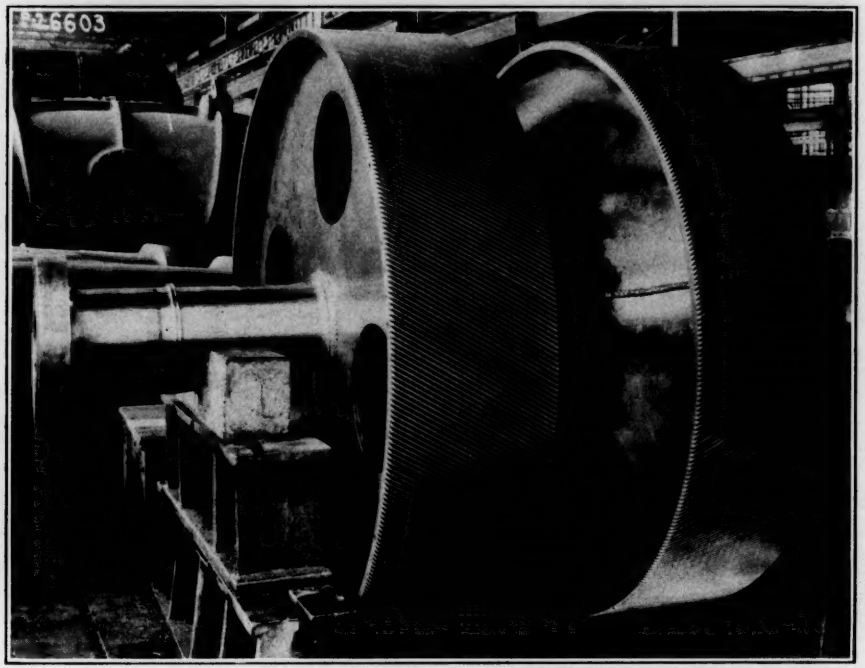

FIGURE 14.—ALL-WELDED GEAR FOR MARINE DRIVE.

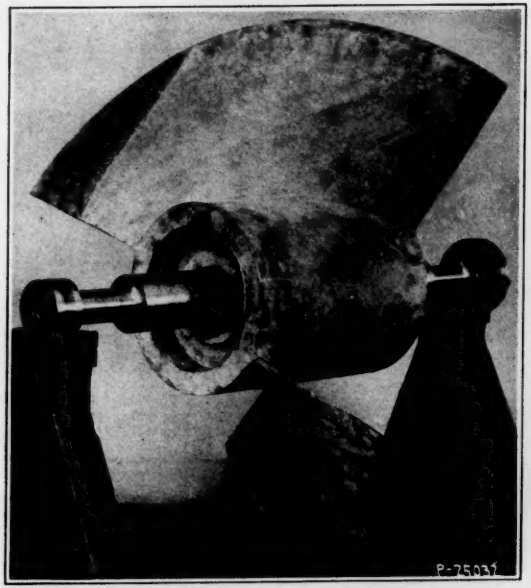

FIGURE 15.—WELDED PROPELLER FOR VENTILATING FAN.

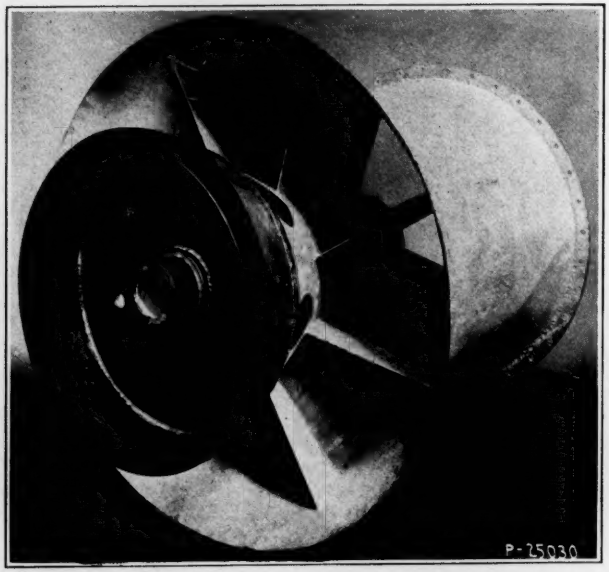

FIGURE 16.—WELDED HOUSING FOR VENTILATING FAN.

metallographic, and corrosion tests (in the case of corrosion-resisting materials), and various pressure tests, such as water, steam, oil or vacuum.

GENERAL DESIGN CONSIDERATIONS.

At the beginning of the ten-year period, and for some time later, there was much tendency to try to carry out existing designs, which in most cases had previously used cast parts, by substituting welding. Probably even before we knew the real fundamental value of radii, curved lines, rounded corners and edges, and beaded edges, in designing and producing iron, steel and nonferrous metal castings, we had made use of these things; they were pleasing to the eye, we were accustomed to them, they were definitely a part of how things should be, and they became more fixed as it became more generally known that such features were necessary for the successful production of castings.

And then designers do not and cannot be changed overnight, and the tendency to rounded edges and curves continued into new designs, that were intended for welding.

And then realization came that if welded construction must in general follow the pleasing curves of the older cast designs, much of the promised economy to be brought about by welding could not be realized. There came the growing conviction that just as the success of casting was a matter of curves and roundness, so was the success of welding, so far as economy was concerned, a matter of straight lines, and angles.

We had been used to the artist of the old school, with his full-fashioned, flowing and pleasing lines. We had to go and sit at the feet of the futuristic artist and accept his more or less harsh straight lines and slashes.

This came as quite a shock to many. The writer recalls a case about seven or eight years ago, being shown a particular new installation at one of our large steel plants. It was a twin installation, but the two units were supplied by two different manufacturers. In the normal development of the plant, one supplier was called upon to furnish his unit nearly a year before the other. For some reason, probably because he used an existing design and patterns, he supplied a unit, the frame of which was composed of castings of

the usual pleasing appearance. The second supplier, probably because of an obvious reason, elected to supply an all-welded construction. And it had straight lines, and square-cut openings and ends, and the welding was not covered, and one can readily imagine the contrast. To one not accustomed to welding, the contrast was somewhat of a shock. It is my impression that both units have continued to render excellent service, and to view the units today would not result in the same effect on one's senses as it did then.

We have made much progress in these matters. We have become accustomed to the straighter lines. We have come to the realization that straight lines need not be harsh, but can be as aesthetic as curved lines.

The matter of finish or appearance is another matter in which we have progressed in a sane manner. For several years it was somewhat of a common practice to grind welds smooth, or to apply a paint filler over the weld, to hide it from view. But there were those who held to the opinion that good welding was not something to be ashamed of, nor something to be covered up, that every effort should be made to make the weld of the best appearance possible and leave it in the plain view of all as welding. This thought prevails today.

SOME MISCELLANEOUS CONSIDERATIONS.

Repairing Steel Castings:—One of the earliest applications of arc welding was the repairing of defects in steel castings. Practically all repairs made ten years ago were with bare wire. Today, any discriminating purchaser and any progressive foundry will use heavily-coated electrodes for such repairs. There is no good in denying that poor repairs have been made, and that there is still much feeling against such welds. However, with the growing use of the welded product, and the utilization of castings in welded construction, a more tolerant and consistent view is now taken of such matters, and the real merits of each case are considered and these, rather than prejudices, dictate the policy to be used.

Steel castings have been specifically referred to, but technique has been developed for arc welding copper-nickel alloys, corrosion

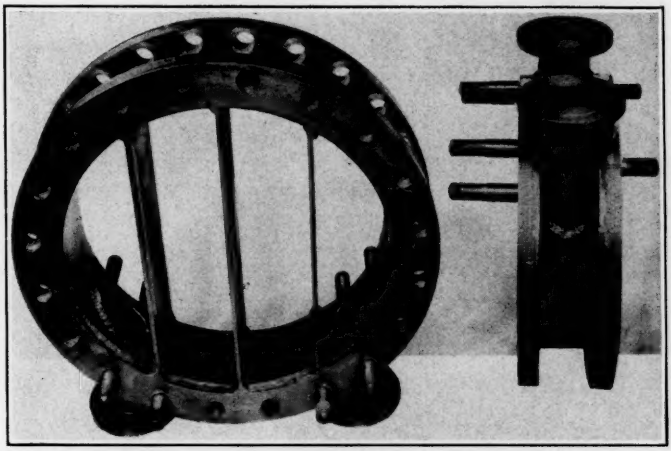

FIGURE 17.—INLET CHANNEL FOR HEAT EXCHANGER.

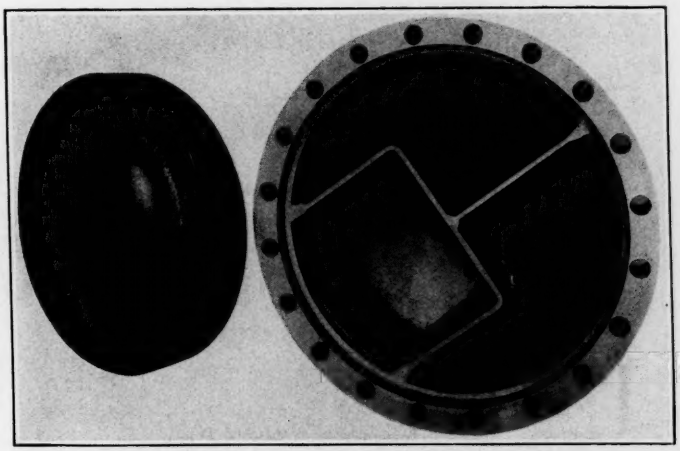

FIGURE 18.—REVERSING CHANNELS FOR HEAT EXCHANGER.

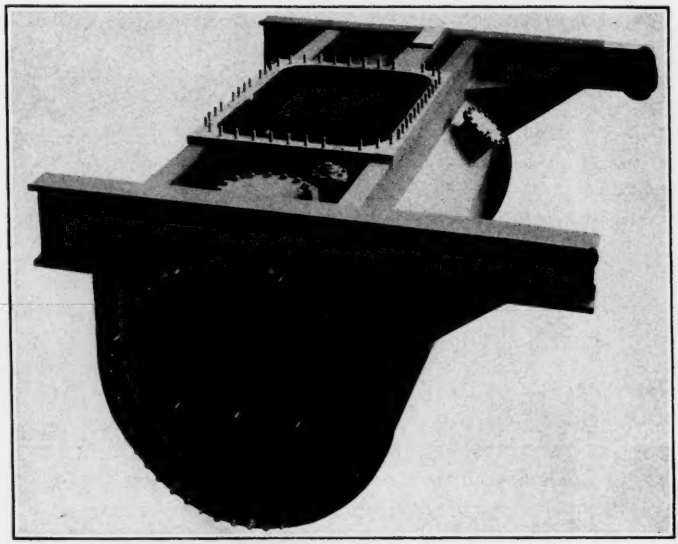

FIGURE 19.—4000 SQUARE FEET MARINE SURFACE CONDENSER.

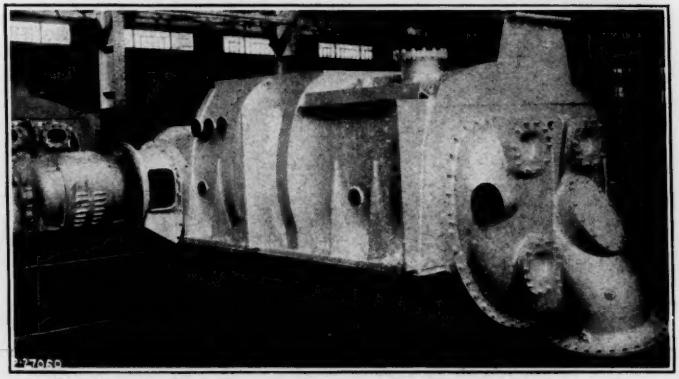

FIGURE 20.—WELDED MARINE SURFACE CONDENSER WITH CAST IRON WATER BOXES.

resisting steels, and many copper base alloys used in marine construction.

Castings vs. Welded Construction:—The past decade has witnessed much discussion and feeling relative to this particular question. It cannot be denied that the general adoption of welding has made serious inroads into foundry production. Genuine competition is a good thing, and should benefit the consumer.

It is of course obvious that much welded construction is not involved in this present discussion. However, the question is a very much involved one in the field of mechanical apparatus. It is true that for some applications, welding offers the best approach; in others a cast product would appear the natural thing. Unfortunate, but true also in many cases, inability to produce acceptable castings has forced the adoption of welded construction; and fear of this situation has resulted in the adoption of welding in others without even trying the cast product.

It appears to the writer, however, that we have lost our better judgment when we more or less blindly adopt welding merely to glorify welding or to advance it commercially, just as we do when we stubbornly stick to cast parts, because we have always used them, or merely to "save the foundry."

The interesting case comes to mind in which a prominent manufacturer brought forth a new welding machine; in which machine he saw fit, for entirely sound engineering reasons, to use a steel casting for the main frame of the motor and generator. This, to some, appeared rank heresy, and it became somewhat necessary for him to defend his action, and to explain why in this new contribution to the art of welding, he had gone so far astray and had stooped so low as to use cast material.

For many designs, the selection as to castings or welded construction becomes largely a question of economics. Complex shapes can be reproduced by either method. But in each method, tools and equipment are necessary. The casting, of course, needs patterns and coreboxes. One often encounters the erroneous feeling that fabricated construction does not require anything of this sort. But for complicated shapes, tools and templates and jigs and other fixtures are quite necessary to the successful fabrication of the

article. Obviously, the number of parts to be produced is an important consideration.

The marine turbine cylinder or casing is a good example, for this discussion. As a rule, the high pressure or intermediate pressure casings are of quite complicated shape, because of nozzle control valves, multiple inlet chambers, and other steam passages. Foundries agree that they are numbered among the more difficult castings that they are asked to produce. The purchasers of such castings are usually very exacting in their demands. The low pressure casings are usually of a much less complicated shape.

Due to the great amount of trouble that has been experienced with such castings, it has frequently been proposed that castings be discarded for the purpose, and welded construction be adopted instead. We must assume that any redesign to change to welded construction would not greatly alter the complicated nature of turbine casings. There is no doubt but that the present complicated shapes can be reproduced in welded construction. Castings will require patterns and the services of skilled foundrymen. Welded construction will require many special tools and fixtures, and the services of skilled mechanics and welders. If a sufficient quantity is involved, to permit of properly "tooling-up" for the job, the welded construction may be made the more economical. If but a few casings are involved, invariably the casting approach will be the more economical.

Designs change rapidly due to service conditions and the desires of the purchaser, and very rarely are there sufficient like units involved at any time to warrant the preparation of the special equipment so necessary to do the work. Standardization is almost out of the question.

Parts of turbine casings have been constructed by welding. The reaction and exhaust portion of the small generating turbine in Figure 2 was welded. Quite a number of these are in marine service. The inlet portion by reason of its more complicated construction was a steel casting. Experience has shown, however, that the matter could be approached more readily by using steel castings, and later designs such as shown by Figure 3 have used castings for both inlet and exhaust portions.

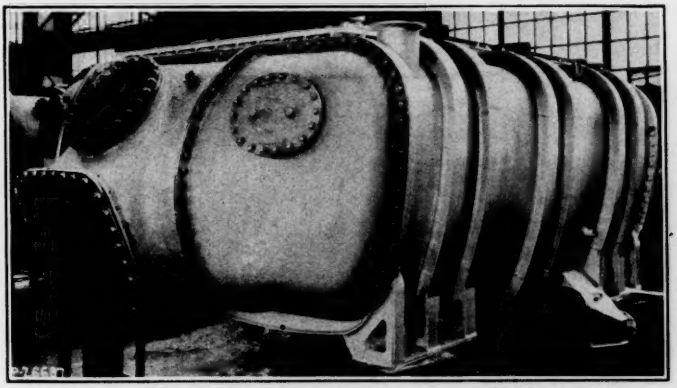

FIGURE 21.—WELDED MARINE SURFACE CONDENSER WITH FABRICATED LIGHT WEIGHT WATER BOXES.

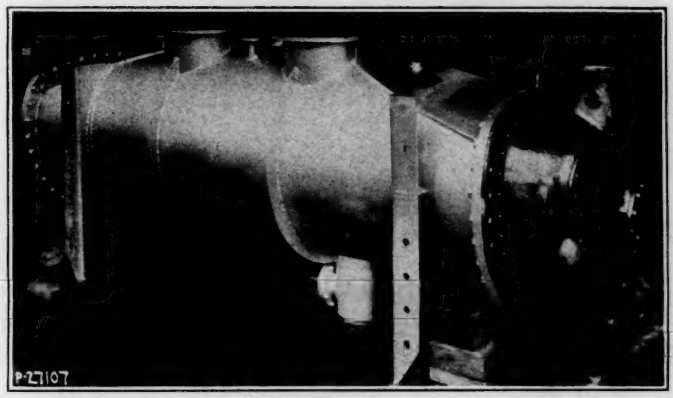

FIGURE 22.—WELDED MARINE SURFACE CONDENSER WITH BRAZED COPPER WATER BOXES.

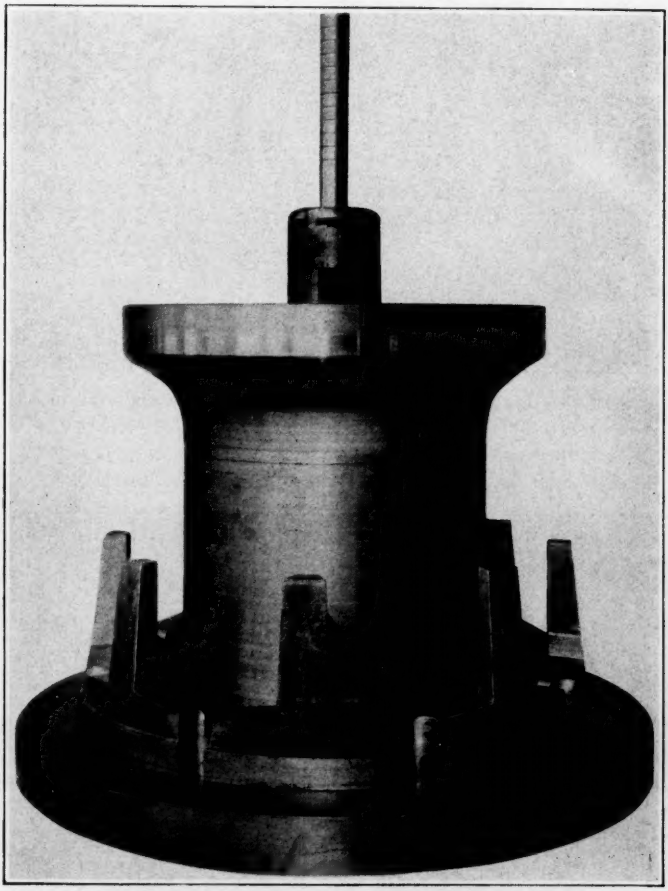

FIGURE 23.—STEEL VALVE WITH WELDED EROSION RESISTING SEAT.

Low pressure turbines, as mentioned above, are usually of simpler shape. More of these have been constructed by welding, but even in these, the practice has usually been to utilize castings for the bladed portions, and build the exhaust portions around the central cast portions. The composite construction appears best for such designs.

Use of Castings in Welded Construction:—The practice of using castings in welded construction had been followed by some manufacturers from the early days of welding. Today, the practice is increasing, and one observes considerable thought being devoted to this feature. Following the same line of reasoning as above, what is true of complete units can be true of parts of units as well. There are many cases in which the design requires shapes that can be produced more economically by casting than by fabricating. Very often, the cast part offers a more reliable piece, or a more practical approach to a given end. Examples of such cases will be given below. Although some codes and specifications prohibit such practice, it is believed that it is entirely sound engineering to do so.

EXAMPLES OF MARINE APPLICATIONS.

Reference has already been made to the generating units in Figures 2 and 3, so far as the turbine casings are involved. The reduction gear housing in each case is of welded construction. In the later design, Figure 3, a change will be noted at the horizontal joint flange of the gear housing. Two steel castings have been used to form the flanges. Each casting makes up the entire flange, with pinion and main shaft bearing housings integral. The use of castings at this point is largely a matter of economy, the best way to produce a required shape that is slightly complex.

The welded bed plates are worthy of mention. Such bed plates were among the first structures to be welded. The lightening of weight in the later design may be noted also.

The welding of steam and oil piping is an important application in land service, which will no doubt find more favorable consideration in the marine field in the future. Where high temperatures are involved, welded joints offer many advantages. Joints are difficult to keep tight under high temperature and high pressure conditions, and welding the joints together where it is practical to

do so appears to be the best solution. Figure 4 shows an interesting assembly of alloy steel castings and wrought steel piping, with all joints to be welded.

Figure 5 shows another application, for land service, but illustrative of what may be done. In this, two carbon-molybdenum cast steel elbows have been welded to the high pressure turbine casing. Permanence of joint is assured.

Welded construction has been especially applicable to electrical apparatus, both for land and marine service. The replacement of the old cast construction of the stator in electric generators, by welding, is one of the outstanding developments of the welding art. Figures 6 and 7 show the construction of a large main propulsion motor for a passenger liner. Figure 8 shows the rotating element of this motor, also of all-welded construction. A point worthy of mention is the welding within the eight round holes in the round disc hub, which welding secures the disc to the flat spokes. This method of welding was found to greatly minimize internal stresses in the wheel.

Figure 9 shows a typical marine motor of 150 H.P. capacity, with welded frame and feet.

A number of examples of marine reduction gear construction are offered. Figure 10 shows a double reduction gear, with welded casing. The main and thrust bearing housing at the lower left is a casting, and several small castings have been used for the pinion bearing housings above. Otherwise steel plate alone has been used.

Figure 11 shows another gear casing, in which the entire upper portion of box-like shape is a steel casting, and the remainder of steel plate construction.

Figure 12 is an example of the upper half of a double pinion gear casing, of all-welded construction.

Figure 13 illustrates further the use of castings in a fabricated construction. In the exposed joint four steel castings have been used. In each case a casting forms a portion of the joint flange and includes a first and second pinion bearing housing. Economy because of shape, and the practical value of fixing positions of bearing centers during fabrication are realized.

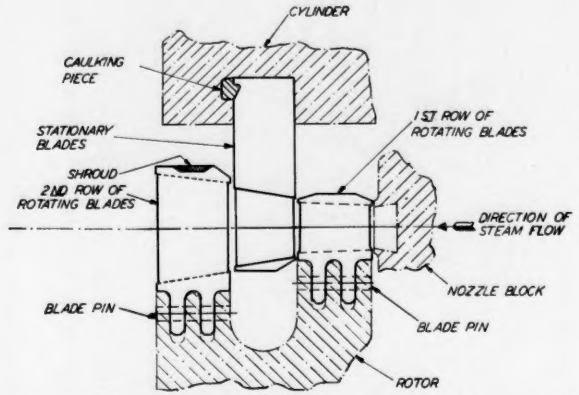

FIGURE 24.—METHOD OF WELDING LASHING SHROUD TO IMPULSE BLADES.

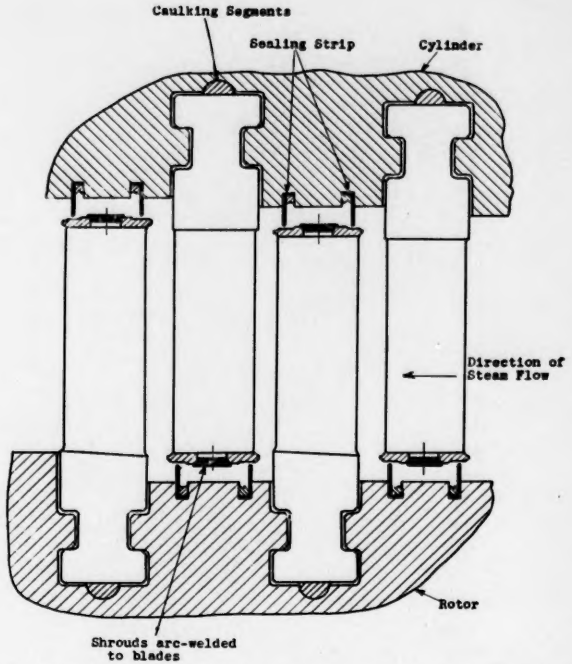

FIGURE 25.—METHOD OF SECURING SHROUDS TO REACTION BLADES BY WELDING.

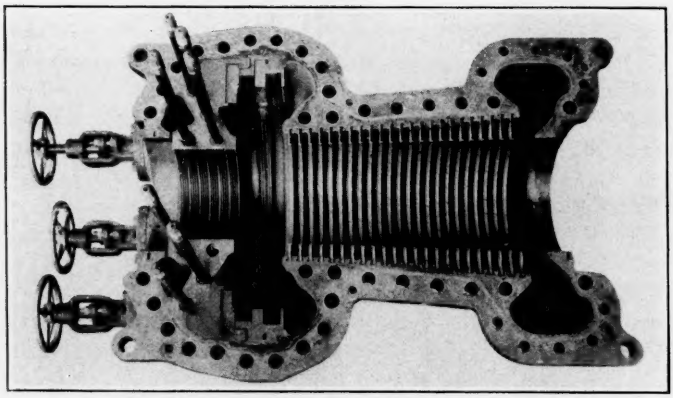

FIGURE 26.—H.P. MARINE TURBINE CYLINDER, WITH WELDED SHROUDS ON BLADES.

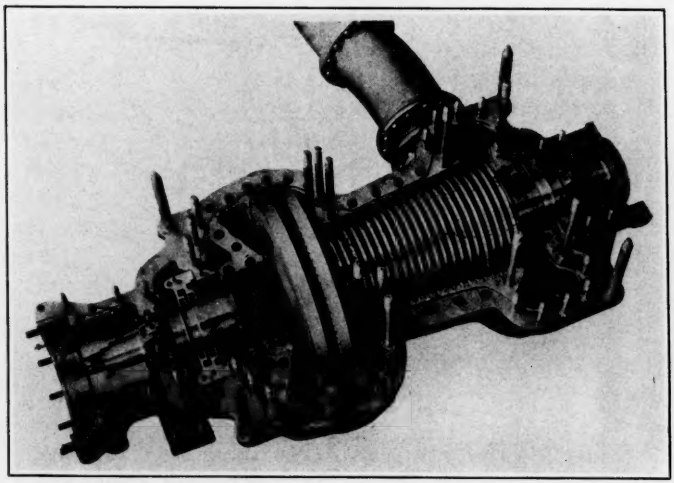

FIGURE 27.—H.P. MARINE TURBINE CYLINDER, WITH ROTOR IN PLACE, WITH WELDED SHROUDS ON BLADES.

In Figure 13 the gear wheel centers are iron castings. Where weight is a controlling factor, the gear wheel centers may be fabricated. This has been done in a number of cases. Figure 14 illustrates one type of such construction. It will be noted that the web has been welded directly to the shaft. If this is done it is well to provide a raised collar on the shaft, and weld to the collar, so that the effect of welding is kept from the main body of the shaft.

The welding art may be said to be largely responsible for making it possible to realize some important developments. There is, for example, the propeller type of blower or ventilating fan for marine use. Figure 15 shows the welded propeller for such a unit. Two or three carefully shaped vanes or blades are secured in spiral grooves in the forged steel hub, by arc welding, to form a very reliable rotating part. This also serves to illustrate the need for proper technique and adequate fixtures and templates, as discussed earlier.

Figure 16 is a type of blower casing showing the further development of the art. The darkened portion to the left is the upper half of the driving turbine casing.

Welding has progressed far in the field of condensers and heat exchangers. Figures 17 and 18 show inlet and reversing channels for heat exchangers. These are excellent examples of what can be done along such lines. The partitions can be readily arranged in devious ways to suit design conditions.

Figure 19 shows a 4000-square-foot marine condenser of all-welded construction, arranged for mounting the high pressure and low pressure turbines directly on the supports provided.

Figure 20 shows another type of marine condenser, of all-welded construction excepting that cast iron water boxes have been used. If weight is a factor, the water boxes may be fabricated as shown by Figure 21 from any of several materials, such as copper-nickel alloy, stainless clad steel plate, or some copper alloys. Or as in Figure 22, the water boxes may be of copper, and welded or brazed with phosphor-copper or silver-phosphor-copper alloy.

The welding art permits the local application of desired metal to various parts. Figure 23 shows a large forged steel valve, the seat of which has been built up of stainless steel. Such locally

applied metal may be copper-nickel alloy, Stellite, many types of corrosion-resisting steels, or other compositions to meet any desired conditions of service. There is wide-spread application of this practice. Other electrodes are available that give an extremely hard, wear-resisting surface of chromium or tungsten steel; and pads, buttons and spots may be created at any desired point in this way.

Welding has been used to advantage in connection with turbine blading, inlet nozzle blocks, and diaphragms for both land and marine turbines.

Figure 24 shows the manner of welding the lashing shroud in impulse blades. Figure 25 shows the manner in which shrouds have been secured to reaction blades by welding, instead of riveting. Figures 26 and 27 show the appearance of such welded shrouds after finish machining in both cylinder and rotor.

Figures 28-29-30 show the manner in which finish machined parts may be joined together to form a desired assembly. Figure 28 shows the individual pieces, Figure 29 assembled ready for welding, and Figure 30 the finish machined block. Figure 31 shows a Rateau diaphragm constructed in a similar manner.

In all the illustrations from Figure 24 through 31 the material being welded is 12 per cent chromium steel, although the so-called 18/8 may be used for some cases.

These examples have been selected from the great many available to illustrate the variety of applications of welding in the mechanical equipment on board ship. These examples will suggest many more possibilities. Surely, the shipbuilder and the designer of marine apparatus has had no small part in the development of the welding art.

CONCLUSION.

Truly, the past ten-year period has been one of progress. Richard, in his "Man and Metals," has remarked that "the idea of progress is comparatively modern; it is peculiarly the impulsion of our own time; the ancients looked backward, we look forward." With the experiences of the progress of the past few years, and with our spirit of research that ever unlocks the doors of greater

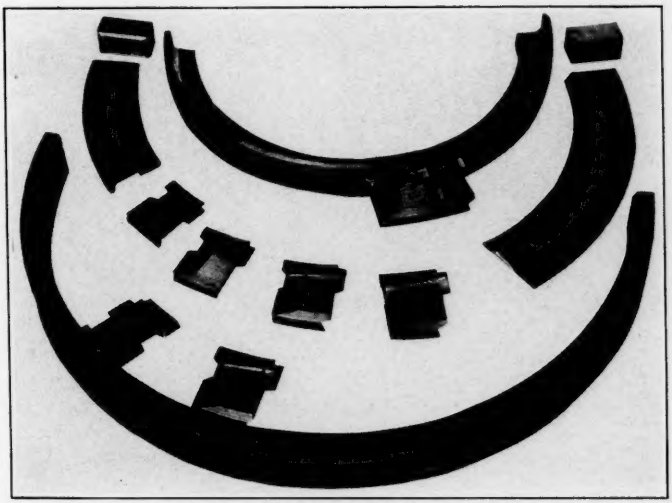

FIGURE 28.—MACHINED PARTS FOR TURBINE NOZZLE BLOCK.

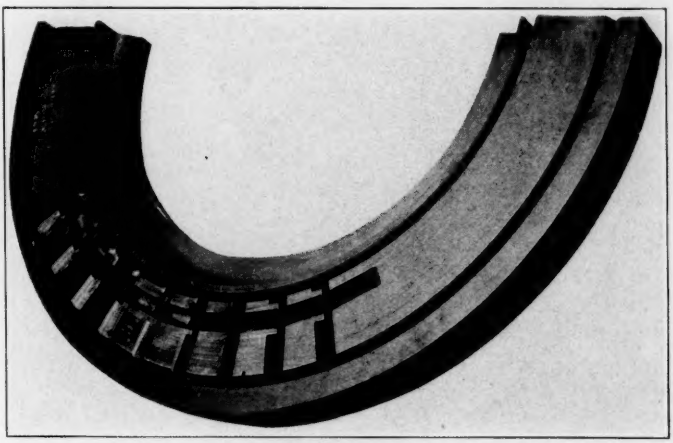

FIGURE 29.—FABRICATED NOZZLE BLOCK READY FOR WELDING.

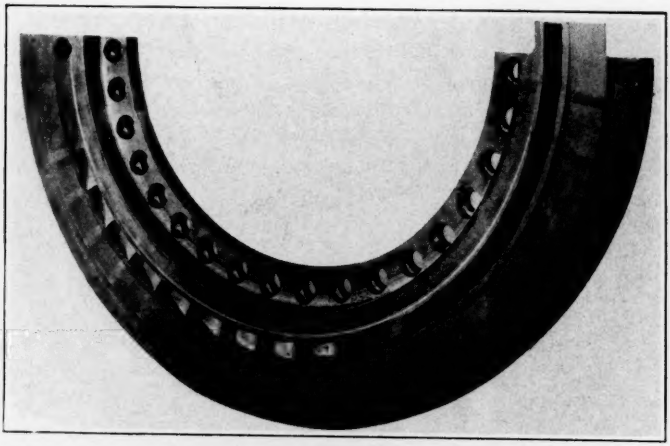

FIGURE 30.—FABRICATED NOZZLE BLOCK FINISH MACHINED.

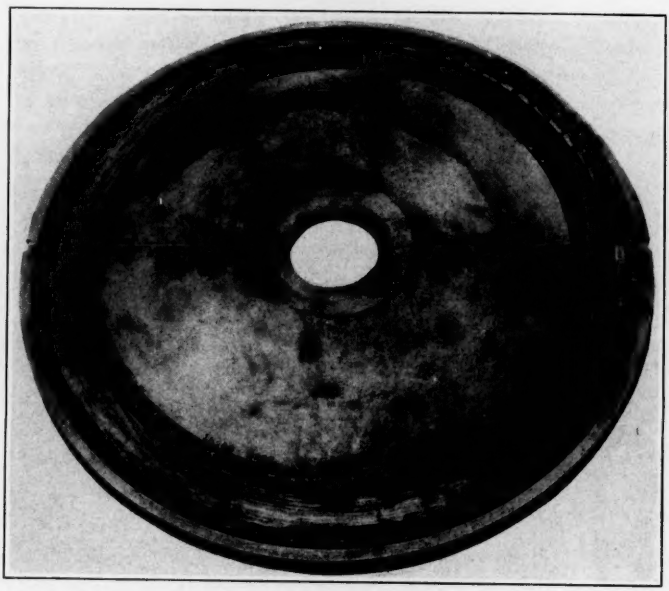

FIGURE 31.—RATEAU DIAPHRAGM AFTER WELDING.

understanding, should we not look forward with confidence to greater and more valuable developments in the years that are directly ahead?

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(1) Llewellyn:—"General Survey of Welding Processes," Symposium on Welding, A. S. T. M., 1931.

(2) Muller:—"How to Select Arc Weld Electrodes," American Machinist, Vol. 80, No. 21, October, 1936, pp. 854-856.

WELDED STRUCTURES.

By Everett Chapman.*

In this article, Mr. Chapman deals with a most important consideration in the production of a successful weld—the characteristics of the parent metal. He points out the necessity for a low carbon content in the steel where welding is necessary, and deals with the stress concentrations which follow the welding operation. His company has been so successful in pioneering the field of welded assemblies that his comment and viewpoint are a definite contribution to an up-to-date discussion of welding and its current problems.

A description of a welded structure, in terms of the physical phenomena that govern its successful completion, would consist of a discussion of three basic phenomena and their inter-relations.

The first important factor is the parent metal, its constituents and properties. The second is a consideration of the sharp notches and cracks that are inherently produced in welded joints. The third is thermal stresses.

The important characteristics of the base material are its chemical composition and uniformity.

UNIFORMITY.

Low carbon steel is generally treated in two different manners in the open hearth furnace, and each treatment produces its own advantages in various applications. The two products are known as rimming steels and killed steels.

As an open hearth heat progresses toward the finish, the mechanism by which various elements are eliminated is essentially chemical oxidation. Carbon and other elements in excess are gradually oxidized down to the desired values and the bath becomes heavily

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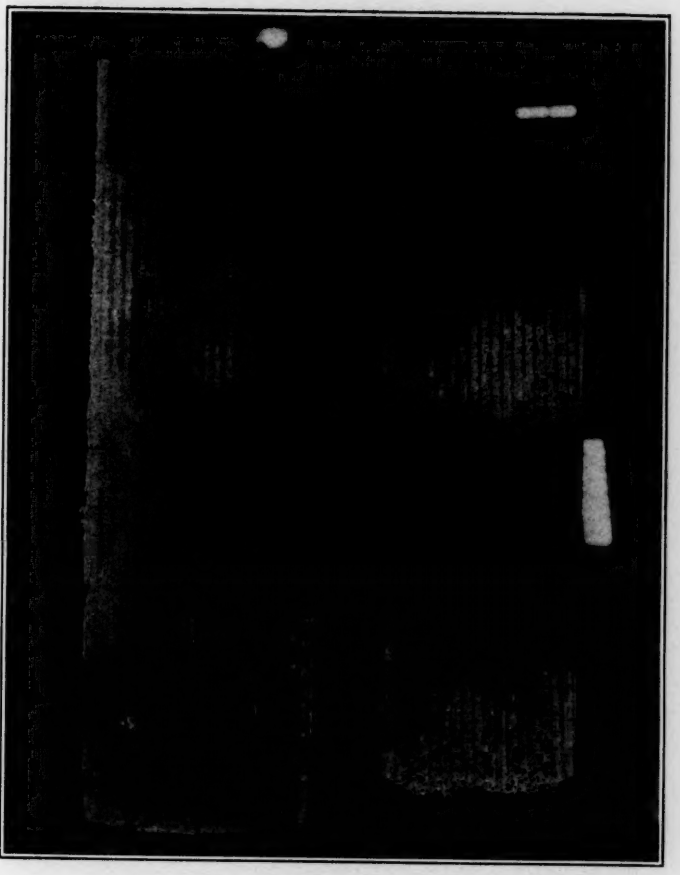


FIGURE 1.

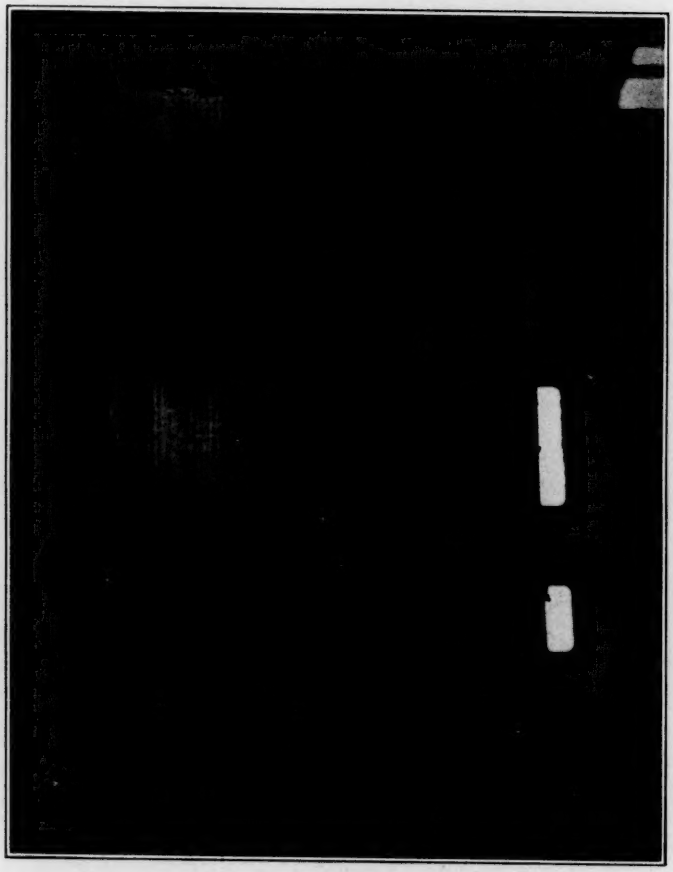


FIGURE 3.

loaded with iron oxide. In the low carbon steels, this process must be taken to the extreme. A rimming steel, when the carbon has reached the desired value, is tapped and poured into molds where it effervesces violently. This effervescence is due to the remaining carbon reacting with the large amount of iron oxide in the steel. As the outside of the ingot solidifies in the mold, a "rim" of very clean low carbon steel is formed. Suddenly, at a point where the temperature equilibrium for this reaction is upset, the remaining gas in the steel precipitates and forms an inside core full of gas bubbles. Within this core are most of the non-metallic impurities in the steel.

Figure 1 (photograph No. 443) shows the cross-section of two typical "rimmed" ingots. This type of steel is excellent for boiler plate because the fine surface conditions of the ingot are reflected in the surface conditions of the resulting rolled plate. For riveted structures, this type of steel has always been used satisfactorily.

However, in dealing with welded structures, it must be remembered that the entire cross-section of the plate, which is a small scale replica of the cross-section of the ingot, must be locally fused by very high temperatures. The behavior of the welding arc, from point to point across the cross-section of the plate, is tremendously affected by the chemical and physical constitution of the plate from point to point.

Most of the sulphur, which is one of the worst gas-producing constituents under the action of the welding arc, is found just inside the "rim" in a rimming steel. When this zone of high sulphur concentration is being fused, small gas bubbles may be formed and the resulting porosity can easily be, and generally is, interpreted as a crack or lack of fusion at the boundaries of the weld deposit. This is one of the major causes for rejection of a pressure vessel. The cost of chipping out and re-welding the joint can offset the lower price of the steel many times over.

Figure 2 (photograph No. 568) shows this effect of a weld zone meeting the line of segregation in a rimming steel. It is a weld completed from one side, with the resulting porosity at the intersection of the weld and sulphur zone.

Now go back to the open hearth heat at the time when the steel was ready for tapping. Silicon or aluminum may be added as the

steel is tapped to deoxidize the entire heat. After this is done, the steel is poured into molds where it quietly solidifies. The iron oxide-carbon reaction does not take place because the iron oxide has been reduced by the silicon. This is a so-called "killed" steel. The impurities are evenly distributed throughout the ingot and there is no evidence of non-uniformity as exhibited in the rimming types of steel. Figure 3 (photograph No. 419) shows a killed ingot in cross-section.

A welded joint made across the cross-section of a plate rolled from an ingot of killed steel does not encounter various compositions from one surface to the other. Killed steel, while more expensive than open steel, is more predictable when considered from the standpoint of an X-ray clean weld.

HARDENABILITY.

Hardenability is the other important characteristic of the base metal. Two important factors hinge on the amount of carbon present in the parent metal. High carbon content, and resulting hardenability, is one factor calling for heat treatment of the finished welded structure, and this same carbon content is responsible for a good deal of shop cracking.

Other alloys bear on these two questions in proportion to their ability to make the steel air hardening. Consider that a steep temperature gradient exists around a weld, due to the high temperature of the arc and the low temperature and thermal capacity of the parent metal. It is obvious that quenched zones exist and the hardenability of the parent metal directly controls the physical properties of the parent metal in these quenched zones. Figure 4 (photograph No. 883) shows the relative magnitudes of these effects in .24 and .40 carbon steels. The various microstructures are shown at a magnification of 100 diameters. The .40 carbon steel exhibits martensite in the quenched zone. The .24 carbon steel is somewhat better although it exhibits a troostitic structure. These hardened zones do not have any ductility and, in combination with the drastic residual stresses that exist in a welded structure, are responsible for the cracking that is experienced during shop fabrication.

Seven years of experience in the fabrication of many types of welded structures has led to the conclusion that carbon content in a fool-proof welding steel should be kept below .17.

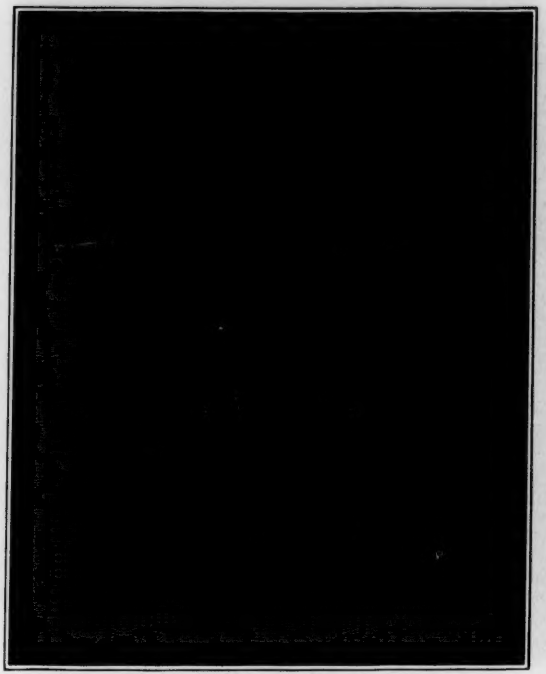


FIGURE 2.

FIGURE 5.

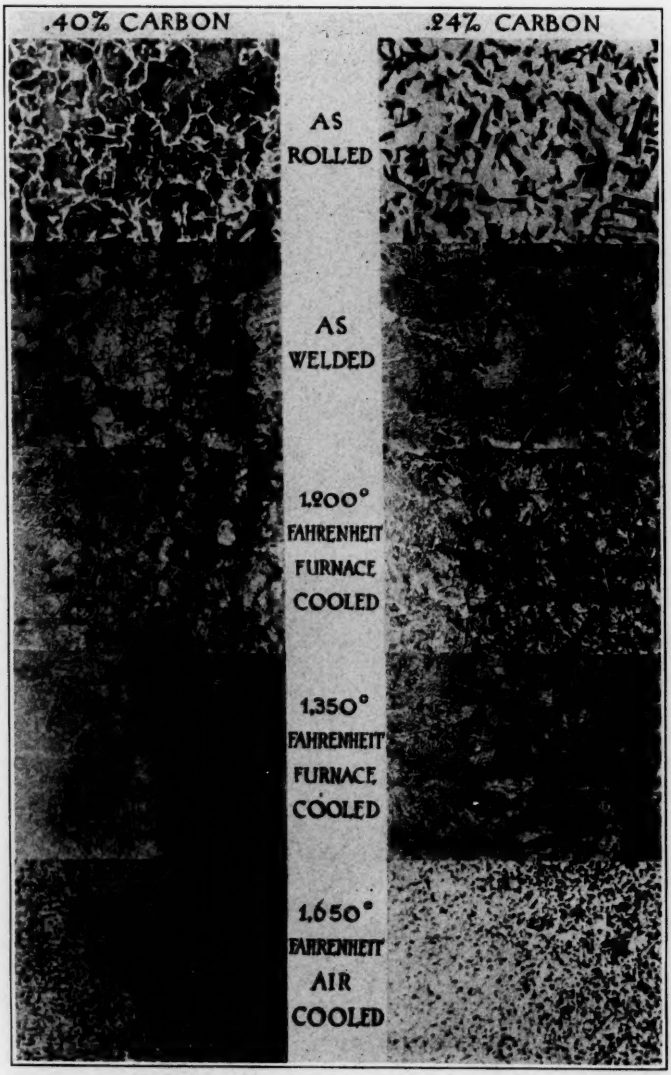

.40% CARBON
.24% CARBON
AS ROLLED
AS WELDED
1,200° FAHRENHEIT FURNACE COOLED
1,350° FAHRENHEIT FURNACE COOLED
1,650° FAHRENHEIT AIR COOLED

FIGURE 4.

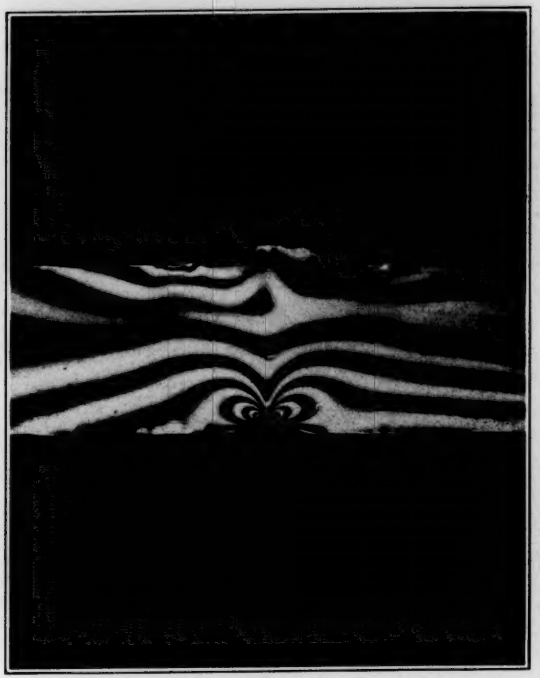


FIGURE 6.

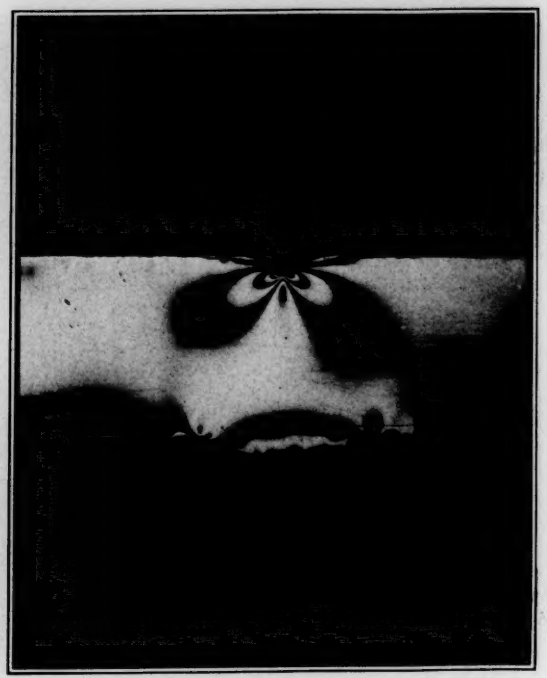


FIGURE 9.

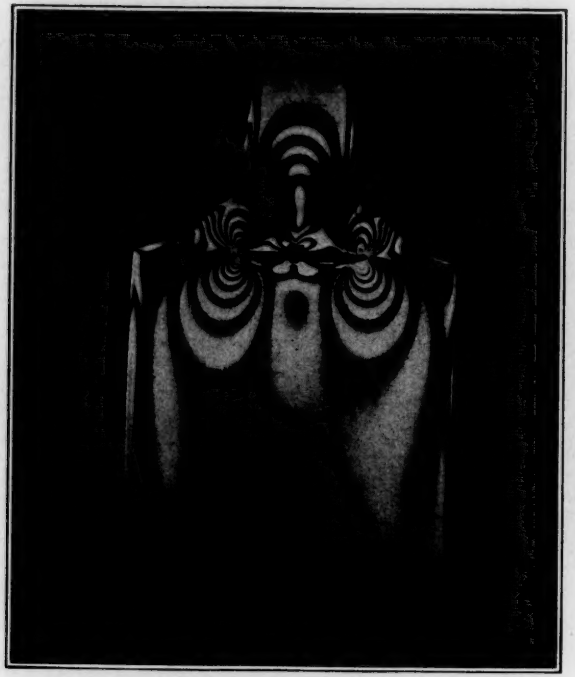


FIGURE 7.

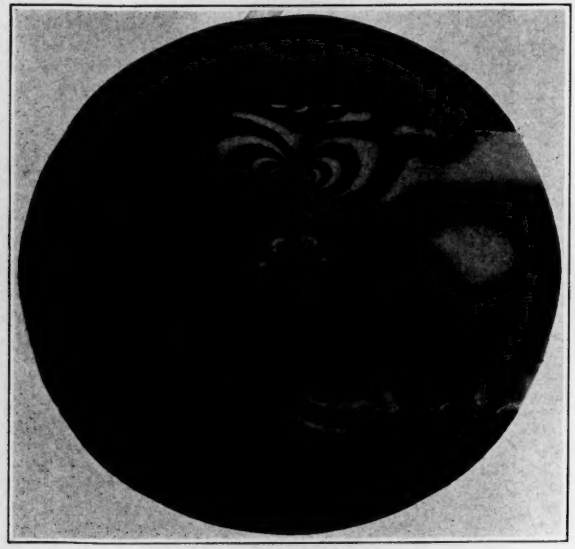


FIGURE 8.

CORRELATIVE CRACKS.

Consider next the nature of the cracks which are produced in the welded structure. Suppose that the edges of two plates are butted together and that fusion is perfected between the two plates over half their thickness. Examine the resulting structure in cross-section. Figure 5 (photograph 568-B) shows such a cross-section. The continuity of its cross-section is suddenly interrupted by a crack which progresses nearly half way through the plate. The fact that fusion is initially partial in a welded joint is one of the most basic troubles in the welding process. These cracks are of almost mathematical sharpness, and they represent a sudden discontinuity in the stress flow in the joint. Under load, these cracks produce areas of very high stress concentration. Particularly in the case of fatigue and vibratory loads, failures will start at these points. Figures 6, 7, 8, and 9 show the stress distribution in a series of typical cracks produced by the very nature of welding. These illustrations are a series of photo-elastic studies executed in bakelite. These cracks spring into existence initially during shop fabrication and it is due to their existence that most shop troubles will occur.

THERMAL STRESSES.

The third important subject, of thermal stresses, is a simply stated, very involved matter. Thermal expansion and subsequent contraction is an irreversible phenomena for non-uniform temperature distributions. It is commonly taught that when a piece of steel is heated, its unit expansion is proportional to the temperature change. The inference has been that the subsequent contraction, as the material cools, results in the same physical dimensions that existed before heating. This is not true and has no significance in all practical cases.

Consider a circular disc, the center of which is heated instantaneously to a finite temperature while the remainder of the disc remains cold. The center attempts to expand at a rate faster than the outside periphery of the circle. The expansion of the center against the restraint offered by the rigidity of the non-expanding rim is about as good an illustration as can be found of the irre-

sistible force meeting an immovable object. Something else definitely happens to the disc when the differential strains reach the yield point of the material. The metal on some circular locus will be actually upset and thereby shortened from its initial dimensions. When the disc achieves a uniform temperature and then starts to cool, the center of the disc is now attached to the external rim by a ring of metal which is shorter than it was before heating. When this disc cools to its original temperature, there will be a resulting stress on this central disc of radial tension and a compression in the external ring of high magnitude. This illustrates the irreversibility of the law of expansion and contraction, and concerns itself with self-imposed rigidity in a single piece of metal due to its differential heating.

Consider the same effect when an external restraint is exerted on a piece of material which is being heated. Heat a one-inch square bar, six inches long, attached at each end to a very rigid foundation of some sort. As this bar is heated, it expands against the extreme rigidity of the connecting pieces and again the metal will be upset as the temperature rises. The bar is now somewhat shorter than six inches in its initial temperature. As it cools, it will exert large forces upon the foundation in the reverse direction. Non-uniform temperature stresses, pulling on an unfused root, will break many a weld before it is completed. This phenomena also accounts for the warping of a structure during welding. It constitutes the greatest reason for furnace stress-relieving after the structure is welded and before it is placed in actual working service.

Another serious product of this thermal stress question is the following: Consider ductility as manifested by a standard .505-inch tension test specimen. As such a specimen of usual steels is pulled it exhibits a great ductility. This is simply shear deformation in the plastic range. Now impose a stress on two faces of a small unit cube and another stress on two faces at right angles of the same cube. Poisson's lateral contraction is now inhibited by the second set of forces. Under such conditions of loading, the material will not show the usual ductility of the standard .505-inch test specimen under a simple axial load. The second set of stresses prevents the shear of the material. Fractures under such loads can be quite glass-like and devoid of ductility. These two dimensional stress

systems are exactly produced in large flat plate structures by local heatings. The stresses of contraction are in two directions as was the temperature gradient that produced them. Thus, the nature of the residual loading due to thermal stresses is a two dimensional system. Under such a system of loading, the material can and may show very little ductility. This same low bi-axial ductility is exactly what is developed in bending thick plates. A 3-inch × 3-inch cross-section can be bent very nicely around a 6-inch pin at one operation. The resulting cross-section shows that at the inside radius the material has spread sideways considerably and at the outside radius, the material has contracted, resulting in a trapezoidal cross-section. In bending a 3-inch plate, 10 feet no inches wide, the lateral contraction and expansion is inbihited by the rigidity of the rest of the plate. Under these conditions, a working ductility of only 4 per cent or 5 per cent can be used, whereas the identical material in a .505-inch test specimen may show a ductility of around 28 per cent to 30 per cent in two inches. The conclusion is that the bi-axial residual stresses resulting from a non-uniform temperature distribution may have robbed the material in the structure of most of its ductility. The two extremes of this dilemma can be expressed as follows:

One is the case where a body is perfectly free to move under the action of the thermal strains, and this case exhibits a minimum of locked-up stress, and a maximum amount of warpage. The other is the case of a structure of circular symmetry, as for instance, a gear with a heavy rim and a web which must be welded to the rim. The weld between the web and the rim produces a radial loading and this particular configuration is very stiff under that type of load. Here is a case where there is no warpage that can be measured but which has tremendously high locked-up stresses. A structure cannot be welded so as to have both low residual stresses and minimum warpage. Something has to give under the action of the thermal strain produced by non-uniform temperature distribution.

Now consider the interaction of these three basic phenomena as a piece is being welded together in the shop. First of all, a metallurgical damage can exist along side of the weld; incipient cracks or rips are introduced in the structure exactly at the non-ductile zone by virtue of the fact that fusion proceeded only to those

points, and indeterminate thermal stresses exist throughout. Is it any wonder that, in poorly chosen material and under a poorly chosen technique, root rips propagate themselves through the weld as fast as the beads can be laid down? One of the most important steps in making a weld is to eliminate the root rip immediately, which means back-chipping the weld before the stress has built up against an increasing rigidity, and resealing the chipped root before proceeding.

The designer of a welded structure and the management of the weldery that makes welded structures are far more responsible for the actual success of the welded structure than the welder. An intensive program of education rather than a blind, final emphasis on the qualification tests of welding operators, is needed to insure the sound working life of welded structures. The physical nature of the phenomena that control the final quality of a welded job are far beyond the responsibility and comprehension of the welding operator. The trouble encountered by an operator in completing a job can be traced generally to the purchase of poor material, indifferent supervision, poor design of the joints to be welded, poor preparation of the joints and a general lack of appreciation of the difficulties and variables involved. As a result, many welders have built up a reputation for witchcraft with their own superiors. Somehow, in some manner, they have managed to complete the job. Around this particular point revolves all the superstition of the welding operator as an artist. The trouble really lies back in the preparation of the design and the purchase of the material involved, which are responsibilities of management. An operator should have a manual dexterity equivalent to the ability to thread a needle at arm's length. He should be able to listen to, and follow, instructions. He should be able to read instructions. Those are his responsibilities.

The following illustrations are representative of the present state of the art:

Figure 10 (photograph No. 859 A) shows a pair of advanced design 500 horsepower marine Diesel engines. These four-cycle reversing engines weigh 20 pounds per horsepower.

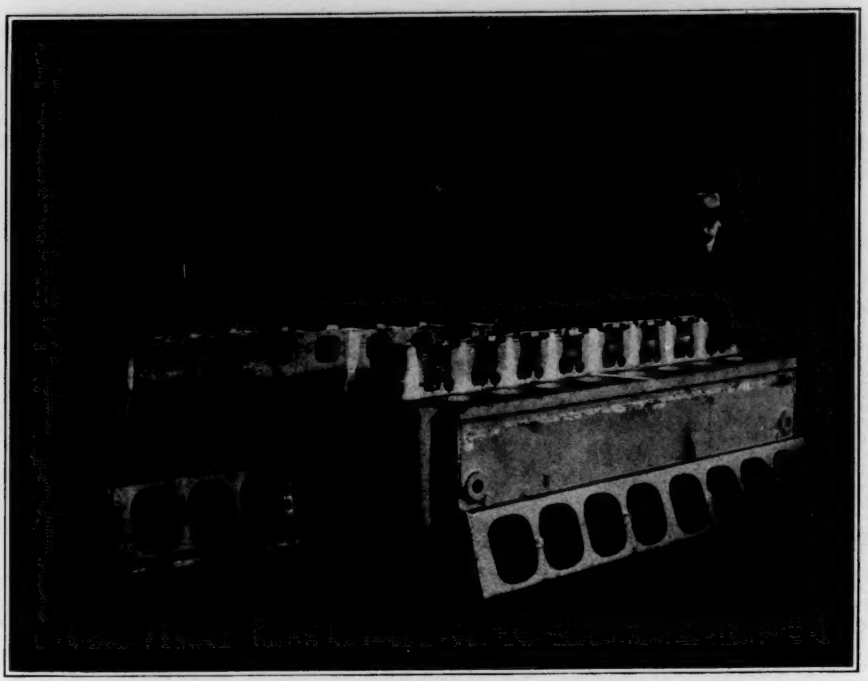


FIGURE 10.

FIGURE 11.

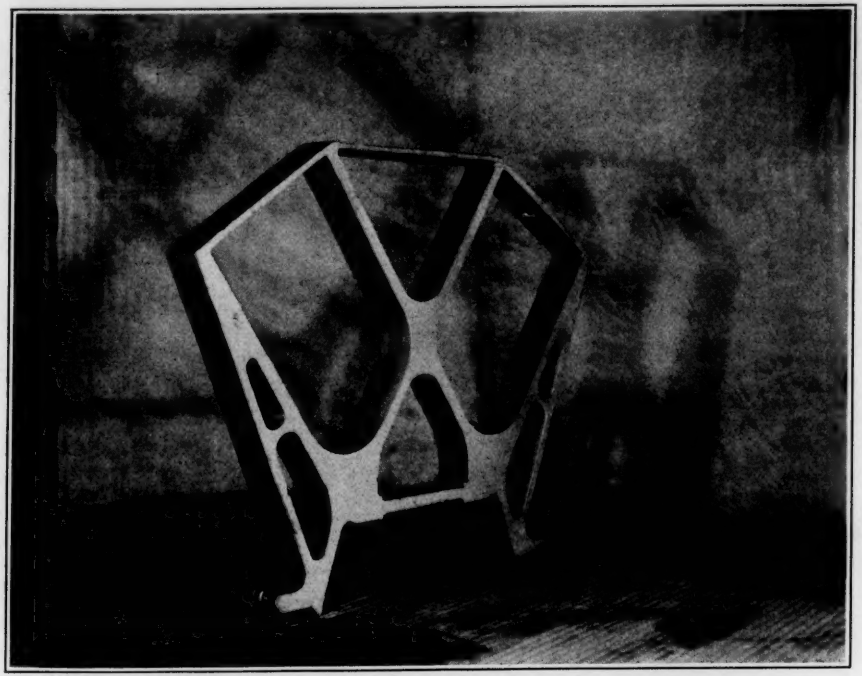


FIGURE 12.

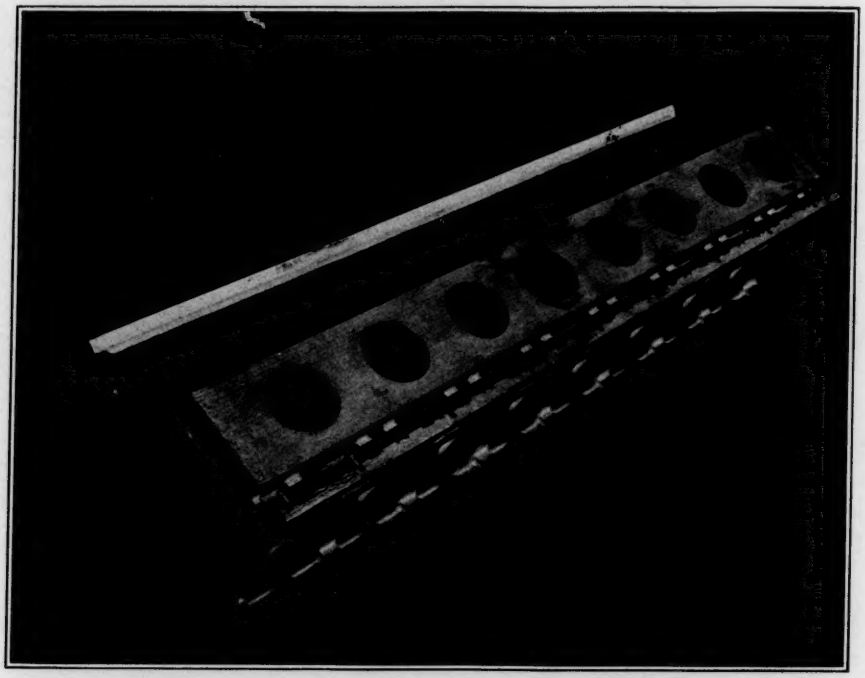


FIGURE 13.

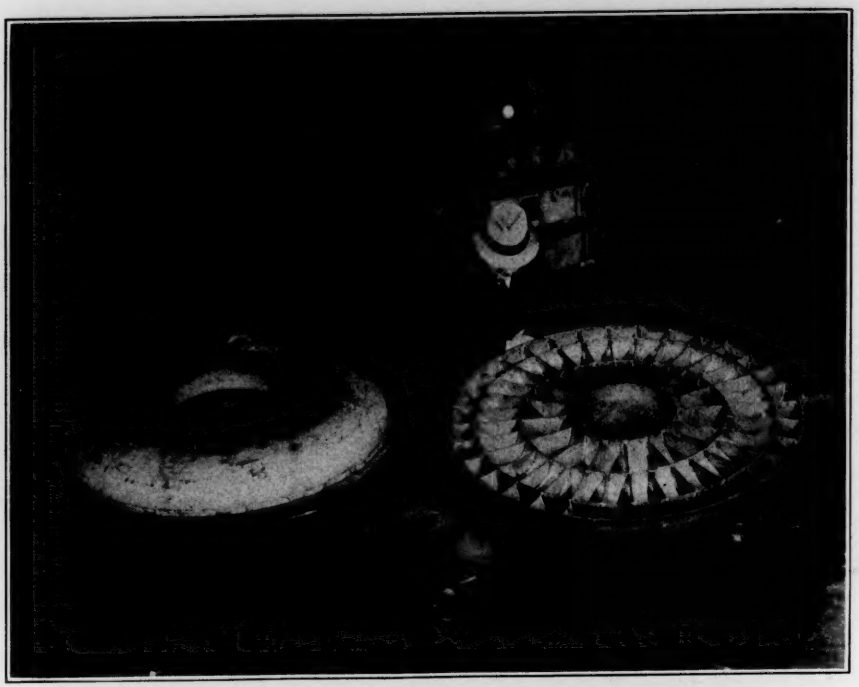


FIGURE 14.

FIGURE 15.

Figure 11 (photograph No. 859 D) shows the use of forgings for the foot construction of these engines. Note the generous use of large radii to achieve a smoothly-flowing structure.

Figure 12 (photograph No. 491) shows the main strength member of a 1200-horsepower V-type submarine engine. It is flame-cut from a low carbon alloy steel and heat treated.

Figure 13 (photograph 522 A) shows a completed welded crankcase for a 1200-horsepower V-type submarine engine. The gas load of 38,000 pounds, almost instantaneously applied, occurring twelve times a second, is transmitted to the main bearing reactions through butt welds.

Figure 14 (photograph No. 863) shows welded parts for oil couplings, used for coupling Diesel engines to driven units. These units provide simple declutching and form an adequate cushion for isolating the mass-elastic antics of the Diesel from the unit it is driving.

Figure 15 (photograph 882 A) shows a typical light-weight, high strength component for high speed railway service. It is made of alloy steel, and one earlier-built similar unit has been through seventeen collisions to date without appreciable damage. Four of these collisions were at speeds in excess of seventy miles per hour.

Editor's Note. A mathematical analysis and estimation of the magnitude of the thermal stresses discussed by Mr. Chapman on page 479, et seq, appears in an article entitled "Temperature Stresses in Flat Rectangular Plates and in Thin Cylindrical Tubes," by J. P. den Hartog, Associate Professor of Applied Mechanics, Graduate School of Engineering, Harvard University. The article was published in the Journal of the Franklin Institute, Lancaster, Pa., August, 1936. It is highly recommended to those particularly interested in following up Mr. Chapman's discussion.

THE REPAIR OF STEEL CASTINGS.

By Hugo W. Hiemke.*

Before radiography opened the insides of metal shapes to the inquisitive eyes of inspectors, a skin or surface examination, and a hydrostatic test, had to serve as guarantees of steel casting perfection. Many times these have proved to be weak reeds upon which to lean, and although much opposition was once aroused when it was proposed to accept or reject castings on the nondamaging internal examination, industry is now awakening to the boon which science has placed at its command, and radiographic examination has become a commonplace. Strange to say, as Mr. Hiemke points out, the use of the undamaging internal examination is now serving to save many castings which formerly would have been rejected by rule of thumb, after a costly machining operation. X-ray and Gamma-ray so definitely outline the limits of porosity, and the length of shrinkage cracks, that it is often safe to chip out and replace the poor metal with a sound weld, thus saving the casting. Mr. Hiemke discusses casting salvage by this method, and concludes with a discussion of the recent advances which have increased our knowledge of stress relief treatments—a development of deepest interest to all foundrymen and welders.

INTRODUCTION.

The following article covering briefly the repair of steel castings is written from the viewpoint of the Naval Engineer. The repair of castings has become of increasing importance for the following reasons:

* The author is the welding engineer of the Bureau of Engineering, Navy Department, Washington, D. C., and is an associate member of the Society.

(*a*) Castings are of more intricate design. Greater economy, more weight saving, more power, and greater maneuverability are demanded of marine machinery, and the design of the fundamental castings has, therefore, changed in such a manner and to such a degree as to greatly increase the difficulty of producing sound castings.

(*b*) The increased temperatures and stresses to which castings are being subjected require that more and more emphasis be placed on the freedom from internal defects.

(*c*) The availability of, and the improvement in, the technique of X-ray and Gamma-ray photography as applied to steel castings has placed in the hands of manufacturers of steel castings and manufacturers and purchasers of machinery a valuable tool for locating defects and providing assurance that defects have been satisfactorily avoided or repaired.

INCREASING IMPORTANCE OF RADIOGRAPHIC INSPECTION.

The welding of steel castings to repair defects has long been practiced. Indeed, the procurement of a complex steel casting without some welding to correct defects is extremely difficult.

Castings intended for steam pressure service have been inspected by three mechanical methods, each of which will disclose certain types of defects, if present.

(*a*) Surface inspection.

(*b*) Machining.

(*c*) Hydrostatic test.

When defects are disclosed, their nature and extent must be determined by chipping and drilling. If the cavity produced by the exploration is small and shallow, the repair of the defect by welding is usually permitted to improve the appearance of the casting, or to restore the machined surface. The Bureau of Engineering General Specifications for Machinery, covering the inspection and acceptance of steel castings, permit the welding of defects which do not reduce the wall thickness of the casting by more than twenty-five per cent.

When the removal of defects in steel castings decreases the wall thickness by more than twenty-five per cent, the casting is subject to rejection, but if the manufacturer so requests, may be referred to the Bureau for final decision. In the past the Bureau and the Bureau's inspectors have rejected hundreds of steel castings requiring repair of defects more extensive than the allowable twenty-five per cent. Leaks which occur on hydrostatic test are frequently responsible for rejection after the casting has passed all other tests and after considerable and costly machining has been accomplished. Hydrostatic test leaks are an indication of defects, the removal of which would necessitate chipping completely through the wall of the casting. The large percentage of rejection of steel castings intended for Naval use has resulted in economic loss to the foundries and to the Navy, and in addition the delay incident to the rejection of a casting in an advanced state of machining has proved very troublesome.

During the past two years the Bureau has permitted a considerable amount of welding in excess of the twenty-five per cent limit of the specifications, *provided that the removal of the defect and subsequent weld are subjected to radiographic examination.*

The limit of twenty-five per cent of the wall thickness previously regarded as the maximum depth to which welding may be permitted may be waived, but only when the repair weld is to be radiographed. In lieu, therefore, the limit to be imposed should be dependent on the location and extent of the necessary weld, and the practicability and probability of providing a satisfactory weld at that location. Each case submitted to the Bureau involving repairs of this type must be judged on its own individual merits and circumstances, and no specific rules can be laid down.

In general, defects which extend entirely through the wall of the casting should first be welded from one side; the first bead of weld should then be chipped off from the reverse side, and rewelded from the reverse side. When welding from two sides is not possible, the repair weld may be made only by activities whose process for welding entirely through the wall from one side only has been approved by the Bureau. When the reverse side is inaccessible

for welding, or the placing and the removal of a copper backing strip, repair welding through the entire wall from one side will not be permitted.

When repair welds in steel castings are radiographed, it is sometimes found that the wall of the casting adjacent to the weld is unsound, while the weld is relatively free of defects. In some cases the additional defects have been repaired by welding and the repaired areas were then reradiographed. In a few cases the defects disclosed adjacent to the weld have been so extensive that salvage of the casting by additional repair was considered impracticable and uneconomical and the casting was rejected. These cases have been infrequent. Ordinarily, *the use of radiography has been the means of salvaging castings, rather than the means of rejection.*

The inspection of a large number of radiographic films of welds in steel castings has led to the inescapable conclusion that the unwelded areas are ordinarily less sound than the repair welds. This has led to a desire on the part of the Bureau to radiograph the critical sections of all important steam pressure castings before machining and hydrostatic test, entirely independent of the radiography of the repair welds. By doing this there is avoided the annoyance and unnecessary expense of extensive machine work on a casting later found to be defective or unfit for further salvage.

When the use of radiography is extended to include any section of a casting, rather than just the sections found to be defective by other means of inspection, it becomes necessary to define the standards of acceptance and rejection, and to lay down certain rules regarding salvage by welding.

The Bureau of Engineering has assembled a proposed set of standard radiograph films, portraying acceptable and unacceptable defects, and setting the limits to which welding will be permitted.

A series of films is used to represent the following types of defects:

(1) Blowholes, or internal porosity.
(2) Cracks, or hot tears.
(3) Internal shrinkage cavities.
(4) Unfused chills.
(5) Unfused chaplets.
(6) Plugs.

The standards require that no cracks, or hot tears, plugs, unfused chills or chaplets, will be permitted to remain in castings for steam pressure service. A certain number of blowholes and scattered internal shrinkage cavities may be permitted to remain in the casting without repair. When cracks, extensive blowholes or other types of defects are shown to be present, they may in most cases be removed, and the cavities produced repaired by welding. With more extensive areas of defects, the casting may be judged to be unfit for salvage and therefore rejected.

The interpretation of radiographic films is of the greatest importance. The value of any observer's interpretation or evaluation of a defect appearing on a film is dependent on his experience with the physical exploration of similar defects on actual castings. After an observer has seen typical defects removed from a casting by chipping or drilling, or as revealed by machining, and has correlated what he observes in the casting with the radiographic film, he will have little difficulty in interpreting radiographs of other castings.

The photographs shown in Figures 1 to 6 indicate the correlation between the appearance of radiographic films and the actual metal after physical exploration.

Figure 1 is a radiograph showing a hot tear and several shrinkage cavities. Figure 2 shows the same area after machining to expose the defects disclosed by the radiograph. Figure 3 shows indication of porosity, and numerous shrinkage cavities. Figure 4 shows the appearance of some of the actual defects after machining. It should be noted that not all of the defects indicated in the radiograph appear on the section in Figure 4. Other sections below the section shown contain other defects, and the radiograph is an integration of all on a single film.

In Figures 5 and 6 are shown the radiograph and physical appearance, respectively, of a screwed plug repair. It is significant that while these plugs stopped leakage under hydrostatic test, they did not provide a satisfactory repair in that objectionable defects still remained.

FIGURE 1

FIGURE 2
B1

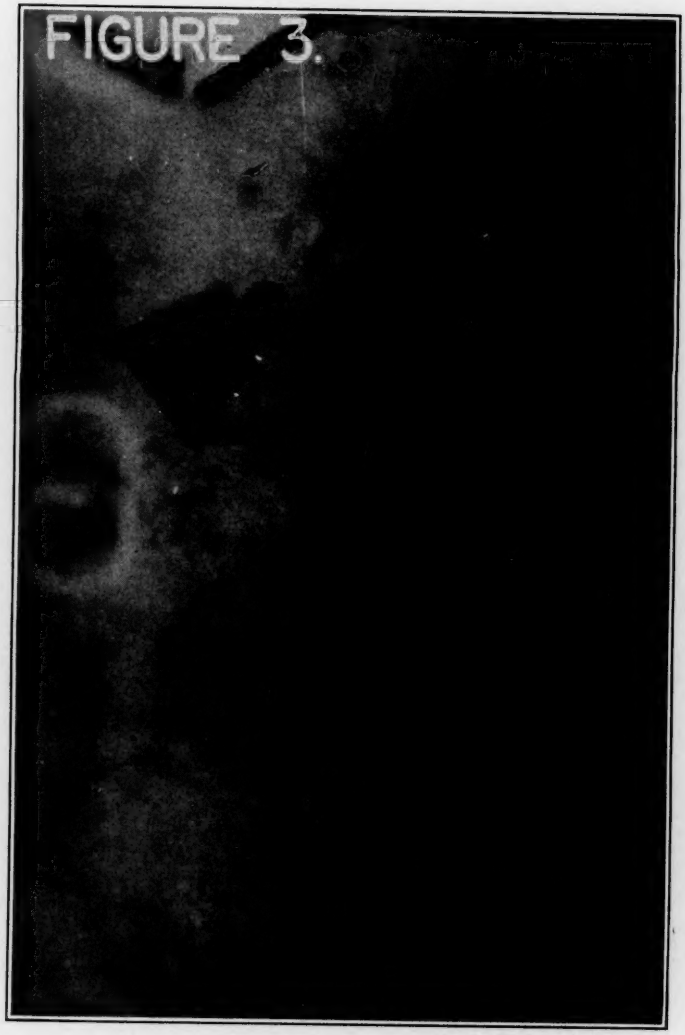
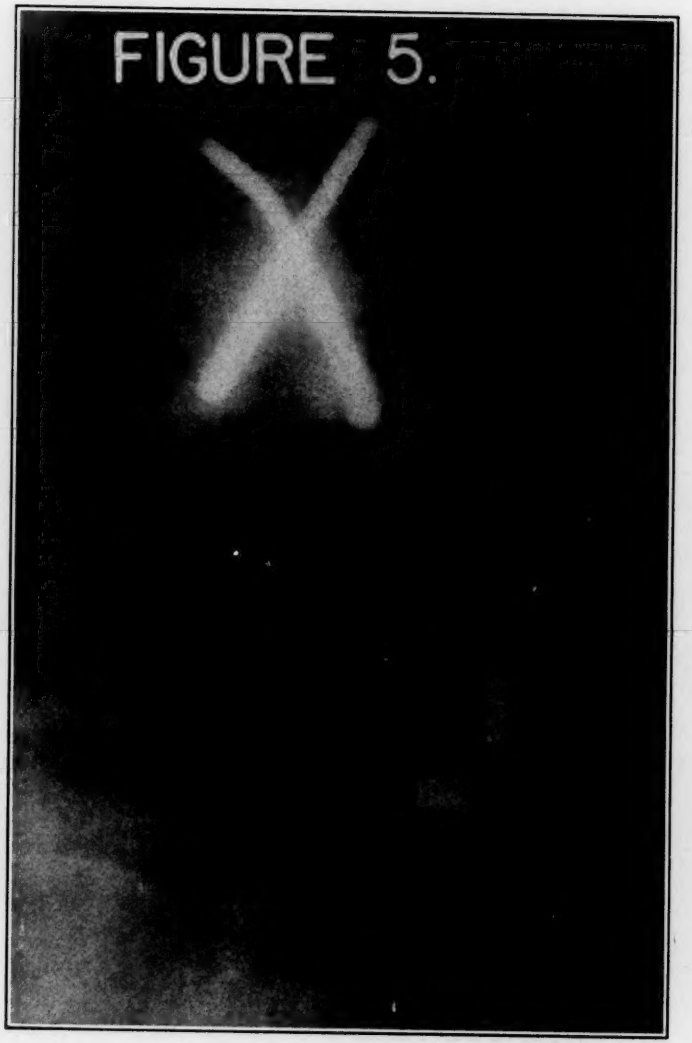


FIGURE 3.

FIGURE 4.
CI

FIGURE 5.



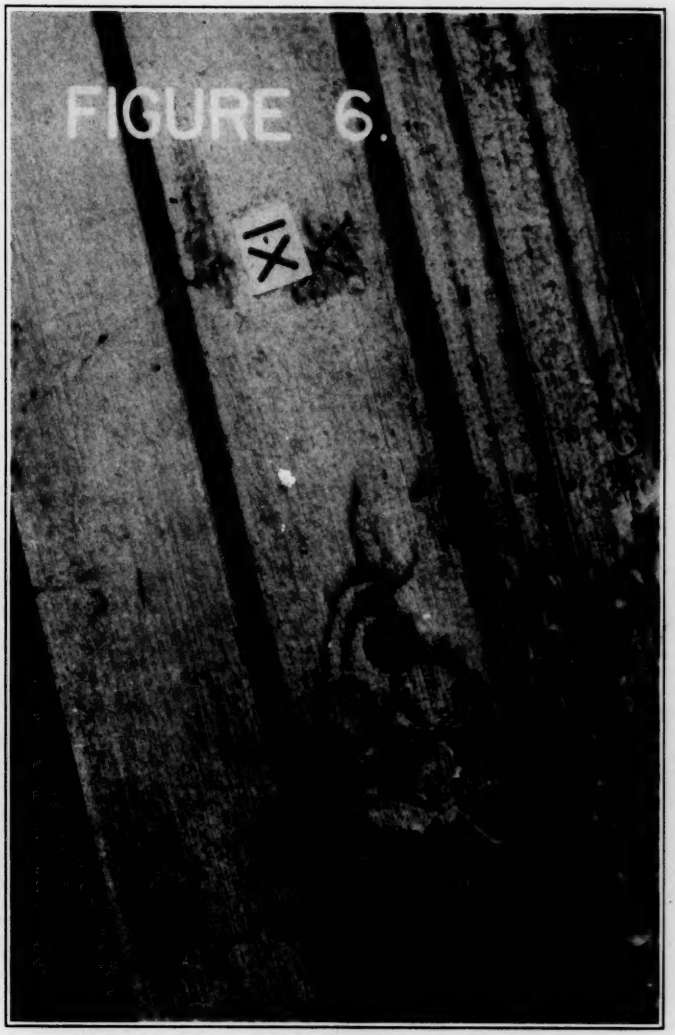


FIGURE 6.
X-1

WELDING PROCEDURE CONTROL.

Major welds, referred to in the previous discussion may be permitted only with the assurance that the weld metal is at least equivalent in physical properties and soundness, to the cast parent metal. In order to safeguard the production of welds in steam pressure castings, the Bureau of Engineering has required that the following types of tests be conducted:

(*a*) Test of electrodes for type approval and batch inspection.

(*b*) Qualification tests for welders.

(*c*) Radiographic tests.

(*d*) Process approval tests.

(Process approval tests are required only for alloy steels.)

All electrodes used on Naval work are batch-tested to insure that those used in production work are equivalent to the original samples tested on type approval test. The requirements for weld metal after stress relief are as follows:

(*a*) Yield point—48,000 pounds square inch minimum.

(*b*) Ultimate strength—60,000 pounds square inch minimum.

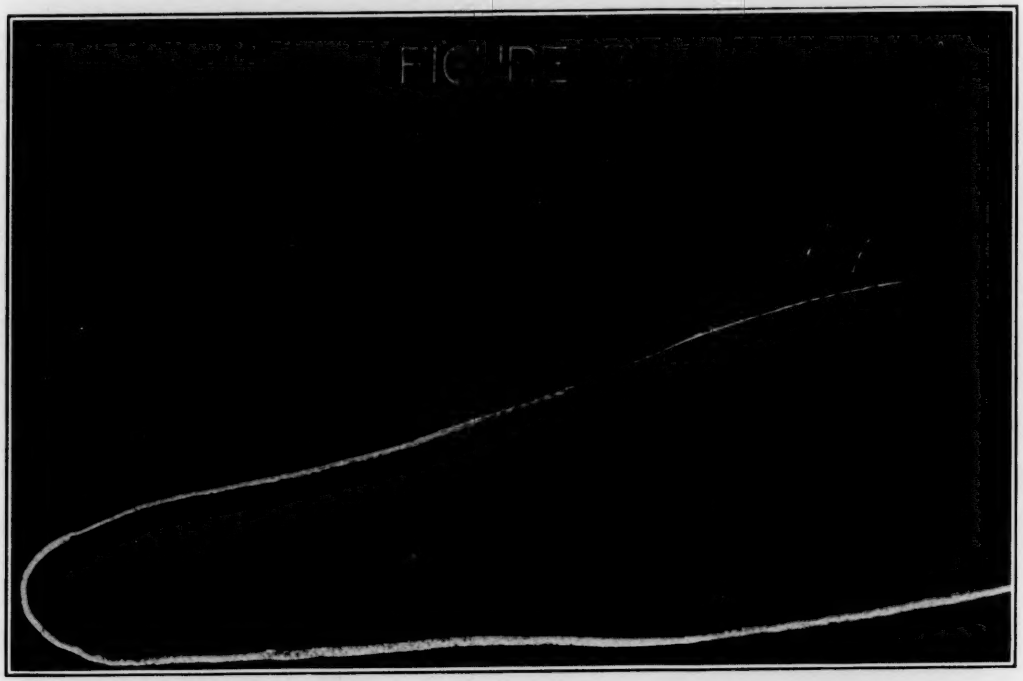
(*c*) Per cent elongation in 2 inches—25 per cent minimum.

All welders employed on Naval construction are required to pass an annual qualification test. Each man is required to prepare a test plate, using approved electrodes. Specimens are cut from the test plate and bent in a standard bend-testing jig. The criterion for passing the test is soundness of the weld, and particularly bonding of the weld to the side wall of the base metal. Any defect exceeding ⅛ inch in any dimension is cause for rejection and disqualification of the welder.

Practically all repair welds in steam pressure vessels are now being radiographed as an additional check on the character of the weld. It is believed that the threefold safeguards of approved electrodes, qualification of welders, and radiography will insure satisfactory welding repairs in carbon steels.

TABLE I.

Material Designation	Specimen Dimensions inches	Tensile Strength Pounds	Proof Stress per sq. in.	Elong. in 2 inches Per cent	Red. in Area Per cent	Bend	
						Angle Degrees	Elongation Per cent
All weld metal	.505″ dia.	62100	48000	38	69.1	.....	.....
Transverse to weld	.965 × .955	63400	.....	34.0	55.7	.....	.....
Cast metal	.505″ dia.	74300	50500	29.7	51.5	.....	.....
Transverse to weld	1.451 × 1.038	Bend Test	.....	.....	.....	75.0	31.0%
Requirements of Specifications	.....	.....	45000	20	.....	.....	30



FIGURE

FIGURE 8

To illustrate the soundness of welding repairs made in steam pressure castings, two radiographs are reproduced to indicate the appearance of a section of a casting before and after welding. Figure 7 shows an area which had an extensive network of hot tears and internal shrinkage cavities. Figure 8 is a radiograph of the same section after welding.

For the welding of alloy steels, an additional (process approval) test is required. This is a more searching investigation of the weld than required by the qualification test. In view of the fact that welding of alloy steels involves a more or less special technique, including preheating, and alloy steel welding electrodes, the process approval test has proven of great value and will undoubtedly be continued.

The physical properties of a weld in carbon molybdenum cast steel are tabulated in Table I. The requirements for the cast metal are also included.

More detailed information regarding process approval tests is given in the article appearing in this issue of the JOURNAL on "Process Approval Tests" by W. C. Stewart.

DISTORTION AND STRESS RELIEF.

The solidification of weld metal is accompanied by a contraction in volume which manifests itself either in movement of the base metal (warpage), or in setting up internal stresses.

Because of the rigidity of steel castings, these internal stresses around welds are likely to be rather high. It can be shown theoretically that the weld metal itself, and the adjacent base metal will be stressed approximately to their respective yield points. The distribution of the stress in the base metal removed from the weld will depend on the relative size of the weld with respect to the casting, and the degree of fixity of the welded joint.

Castings which are welded and not stress-relieved are likely to warp either,

(1) While machining, due to removal of some stressed metal.
(2) During hydrostatic test, when the working stresses are superimposed on the internal stresses, causing yielding.
(3) In service at elevated temperatures due to creep.

In order to relieve these stresses the Bureau of Engineering requires that castings which have been welded be heated in a furnace to a temperature of 1100-1200 degrees F. for one hour per inch of thickness and furnace cooled to a temperature below 500 degrees F. This treatment will reduce internal stresses to a value below 5000 p.s.i.

In addition to its function in relieving internal stresses, this heat treatment acts as a toughening treatment on the weld and the base metal affected by the welding.

It occasionally happens that a casting which has successfully passed all inspection tests, develops defects while finish-machining. If such castings were to be welded, and stress-relieved at 1150 degrees F., they would no longer be useful for the purpose intended, because of probable heavy scaling of the machined surface, and warpage during heat treatment.

In order to determine a procedure of stress-relief after finish-machining, which would partially or wholly relieve internal stresses, and at the same time not warp the casting beyond hope of salvage, the Bureau conducted two series of tests: firstly, to determine the effect of time and temperature on residual stresses, and secondly, to determine the amount of warpage produced by the desired time and temperature of stress-relief.

By an ingenious method, devised by Mr. W. C. Stewart, of the Engineering Experiment Station, under the direction of Captain O. L. Cox, Director of that Station, the residual stresses remaining in steel, originally stressed to its yield point at room temperature, were determined after being stress-relieved at various temperatures and times. Figure 9 indicates the results obtained on a steel having a yield point of approximately 40,000 p.s.i. Figure 10 is a three dimensional plot of the same data. It will be noted that temperature is far more effective than time in reducing internal stresses. The reduction of stresses is produced by plastic yielding, caused firstly by the reduction of yield point with temperature, and secondly, by creep under prolonged loading at the elevated temperature.

The effect of this treatment on three finish-machined castings was determined at the Navy Yard, New York, under the supervision of Lieut. Garvin and Mr. N. A. Kahn. These high pressure castings, which required extensive welding after machining, were

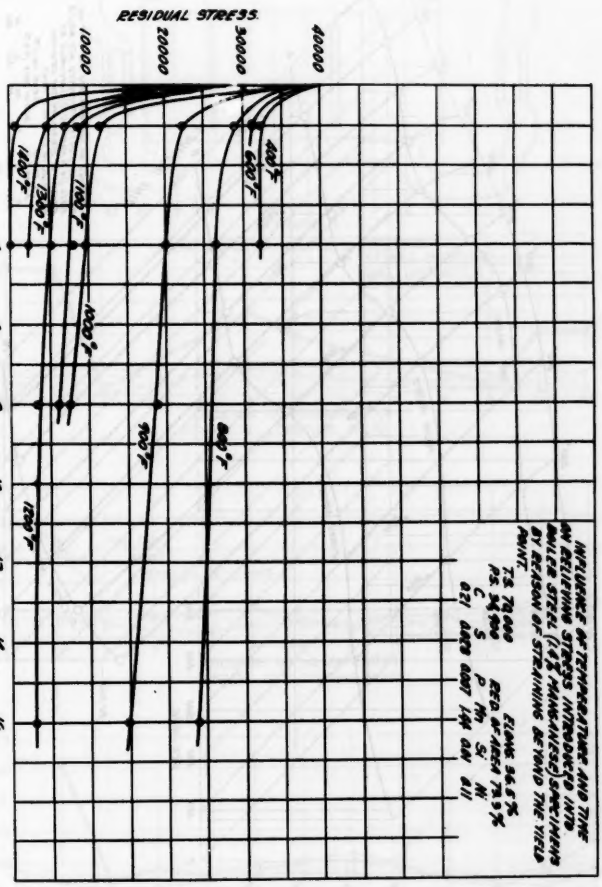

INFLUENCE OF TEMPERATURE AND TIME ON RELIEVING STRESS INTRODUCED INTO BOILER STEEL (1/2" RING-INSERT) BY REASON OF STRAINING BEYOND THE YIELD POINT.
RESIDUAL STRESS.
10000
20000
30000
40000
400°F
600°F
800°F
900°F
1000°F
1100°F
1200°F
1300°F
1400°F
2
4
6
8
10
12
14
16
TIME AT TEMPERATURE-HOURS.

FIGURE 9.

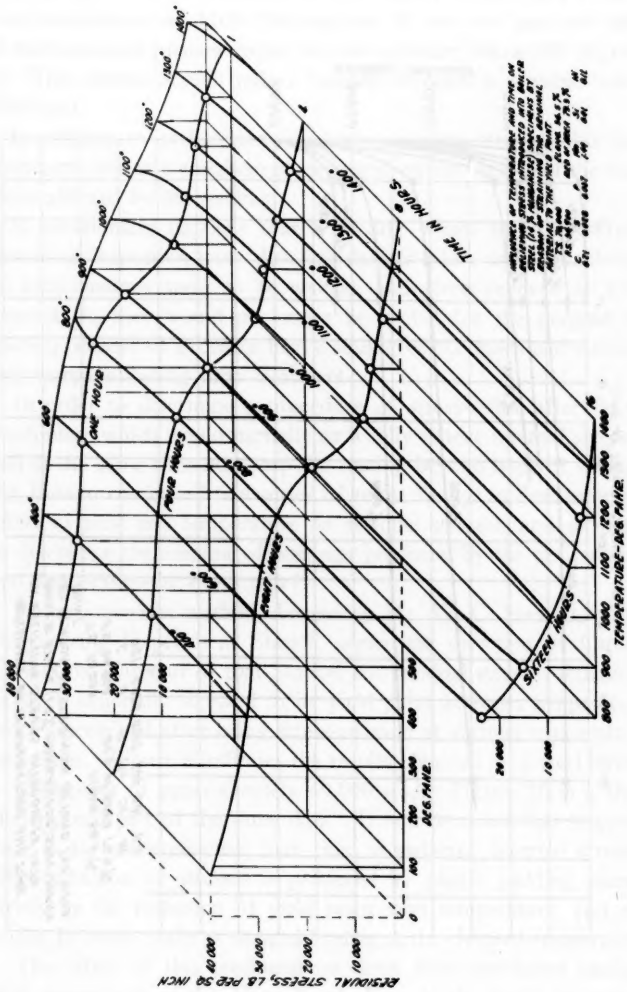

RESIDUAL STRESS, LB. PER SQ. INCH
40 000
30 000
20 000
10 000
0
DEG. FAHR.
TIME IN HOURS
SIXTEEN HOURS
TEMPERATURE-DEG. FAHR.

FIGURE 10.

DISTORTION CAUSED BY WELDING AND STRESS RELIEVING.

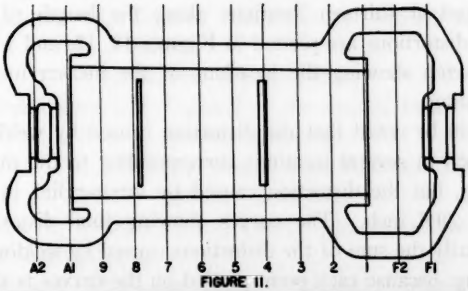


FIGURE 11.

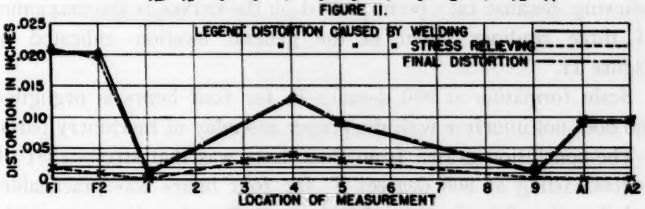


FIGURE 12. CASTING NO. 15

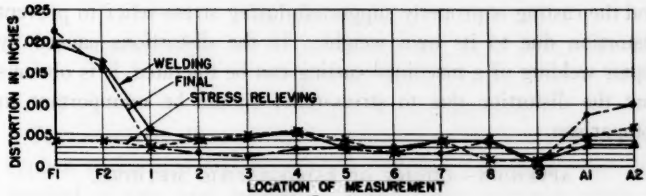


FIGURE 13. CASTING NO. 91

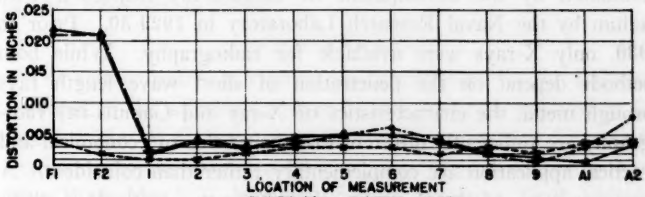


FIGURE 14. CASTING NO. 95

accurately measured before welding, after welding, and after stress-relief at 900 degrees F. for four hours. The distortions were measured at thirteen locations along the length of the casting. These distortions are plotted in Figures 12, 13, and 14. Figure 11 is a sketch showing the locations of the measurements taken on the casting.

It will be noted that the distortion caused by welding exceeded .020 inch in several locations corresponding to the most extensive welding, but the distortion caused by stress-relief in no case exceeded .006 inch. The curves showing total distortion are not necessarily the sum of the distortions caused by welding and stress-relieving, because each point plotted on the curves is the maximum of three readings taken in the general location indicated in Figure 11.

Scale formation at 900 degrees F. for four hours is negligible and does not interfere with the proper assembly of machinery parts.

The conclusion drawn from these tests was that stress-relief of a steel casting at 900 degrees F. for four hours was practicable, and that the distortions produced were of such a low magnitude that they could be disregarded, if the welding is carefully done, and the casting is properly supported during stress-relief to prevent distortion due to its own weight. If the distortions caused by repair welding of a machined casting can be tolerated, it is obvious that the distortion due to stress-relief should be unimportant in comparison.

APPENDIX—CHOICE OF RADIOGRAPHIC METHODS.

The use of radiography for inspection of steel castings was stimulated by the development of Gamma-ray inspection with radium by the Naval Research Laboratory in 1929-30. Prior to 1930, only X-rays were available for radiography. While both methods depend on the penetration of short wave length rays through metal, the characteristics of X-ray and Gamma-ray radiography are sufficiently different that their fields of economical and practical application are complementary rather than coincident. A short summary of the characteristics of the two methods is given in order to illustrate the points of difference, and to evaluate their fields of usefulness.

The X-ray method of radiography has the following advantages and disadvantages:

(*a*) Advantages—(1) Greater sensitivity in sections up to 2 inches.
(2) Shorter exposure time.

(*b*) Disadvantages—(1) Fogging of the film of heavy sections reduces sensitivity.
(2) Equipment requires power input, and upkeep maintenance.

The Gamma-ray method of radiography has the following advantages and disadvantages:

(*a*) Advantages—(1) Less contrast produced where radiographing thick and thin sections simultaneously, makes radiograph of unequal sections possible.
(2) Radium salts are continuously active and require no power input nor upkeep maintenance.
(3) Freedom from fogging by secondary radiation, makes this method applicable to heavy sections.

(*b*) Disadvantages—(1) Less sensitivity than X-ray on sections less than 2 inches.
(2) Longer time of exposure.

To summarize, Gamma-ray radiography is most advantageously applied to unequal and very heavy sections, and X-rays are best adapted to thin and uniform sections. The exposure times of X-rays are measured in minutes, while the exposures for Gamma-ray are measured in hours.

ACKNOWLEDGEMENTS.

The author desires to express his appreciation for the assistance rendered in the solution of some of the problems involved in this study, to Mr. W. C. Stewart, of the Naval Engineering Experiment Station, to Lieut. Garvin and Mr. N. A. Kahn, of the Navy Yard, New York, Mr. J. E. McCambridge, of the Navy Yard, Philadelphia, and Lieut. Commander O. E. Grimm and Mr. K. D. Williams, of the Bureau of Engineering, Navy Department, Washington, D. C.

THE WELDING OF PRESSURE VESSELS.

By James Campbell Hodge.*

Doctor Hodge is well-qualified to speak with authority on the welding of all pressure vessels, and in particular, on fired pressure vessels, where the demand for safety assurance transcends all other considerations. His research work, conducted for his own company from the very start of this branch of the welding art, his work on the Boiler Code Committee of the American Society of Mechanical Engineers, and his many contributions to the welding bibliography, have given him an international reputation. The discussion in this article is confined to welding of the highest class, and the author deals with the safeguards which have been found most efficacious, and the metals and technique which have been developed over some ten years of research, and six of actual service experience in industry.

In 1930, fusion-welded joints for the boiler drums of three scout cruisers, *Minneapolis, New Orleans* and *Astoria,* then under construction, were accepted by the Bureau of Engineering, U. S. Navy, this action representing the first approval by an official engineering authority of fusion-welded vessels for high pressure and high duty service. In the subsequent six-year interval, such construction has become generally recognized in this country, formal rules and specifications covering the construction by fusion welding of boiler drums and other miscellaneous pressure vessels having been adopted by the American Society of Mechanical Engineers, the American Petroleum Institute, and the Bureau of Navigation and Steamboat Inspection of the Department of Commerce. Vessels welded in accordance with these rules are generally accepted by the various municipal and state authorities and by insurance companies. So rapid has been the application of

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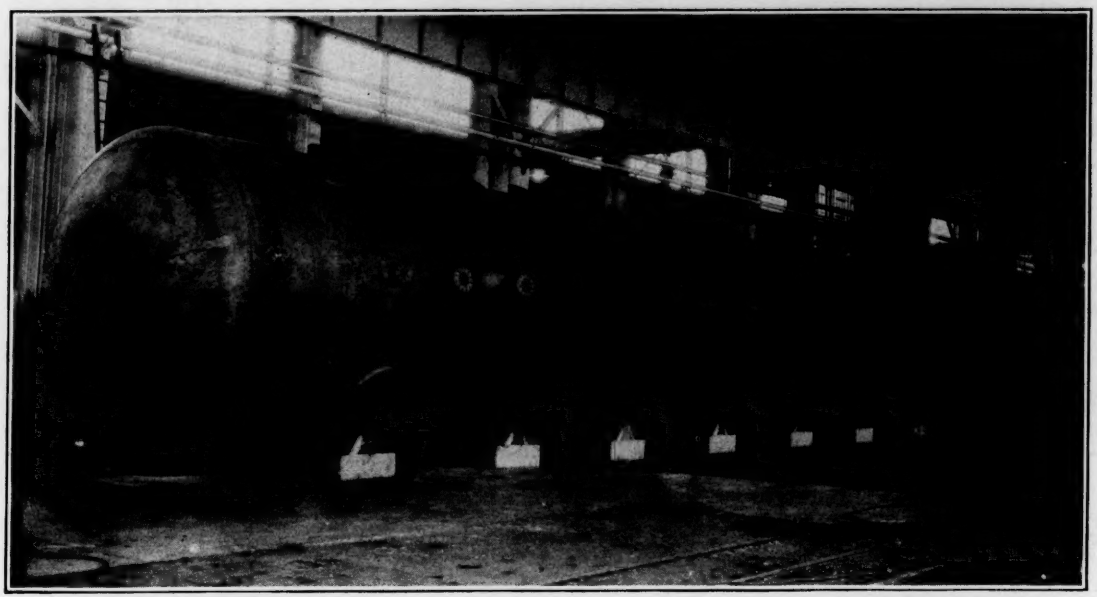


FIGURE 1.—OIL REFINING BUBBLE TOWER 12 FEET O. D. × 90 FEET LONG × 1¼-INCH THICK PLATE. WORKING PRESSURE, 150 POUNDS PER SQUARE INCH. OPERATING TEMPERATURE, 700 DEGREES F. WEIGHT, 380,000 POUNDS.

fusion-welded construction, that the older methods of joining by riveting and forge-welding have been practically completely replaced; so rapid the development of the welding art in this application, that vessels with wall thicknesses up to five inches to operate at 1450 pounds per square inch pressure in power boiler service have been built, thus successfully invading a field of drum construction, well beyond the thickness limits for satisfactory riveted or forge-welded joints, for which high priced forged seamless drums had heretofore been necessary.

This complete and rapid change in conventional pressure vessel jointing methods resulted from the inherent advantages of the fusion-welded joint over the older methods. These advantages have been fully discussed by the author in a previous issue of the JOURNAL [1] but are briefly enumerated as follows:

(1) Elimination of the thickness limit of approximately 2¾ inches for successful riveting and of leakage difficulties experienced with riveted joints at the higher pressures.

(2) Elimination of the thickness limit of approximately 2 inches for successful forge-and-hammer welding and of the hazard involved in service with a joint of this type which can not be satisfactorily tested.

(3) Elimination of the possibility of caustic embrittlement of riveted boiler drum joints.

(4) Economy in weight by reason of the higher joint efficiency attainable with the welded joint and by elimination of buttstraps, rivets, etc.

(5) Greater flexibility in design, permitting a uniform or at least more gradual stress distribution from member to member of the welded vessel and avoiding sudden changes of section which characterize the various types of riveted joints.

(6) Elimination of all fabrication stresses in the completed welded vessel by means of a final thermal stress relieving treatment which cannot be applied to structures involving riveted joints.

The above assumes that welded joints of unquestionable quality may be uniformly obtained under production conditions. Before the acceptance and application of fusion welding to pressure vessel construction, much research and development work had, naturally, to be performed. A welding process or processes had to be de-

veloped which would produce welded joints having mechanical properties equivalent to those of the parent plate material. A testing procedure had to be devised for assuring that welds made in production were of uniform quality and free from defects which might affect the performance of the welds in service. This involved the development and application of non-destructive testing methods, particularly the radiographic method, to their present advanced state. It was necessary to demonstrate the ability of welded vessels to withstand normal service loads, and for this purpose a number of full-sized welded drums were tested to destruction by internal static hydraulic pressure. Tests of this nature were made by various manufacturers, the welds in all cases performing as homogeneous parts of the vessel under the deformation caused by the internal bursting pressures. The deformation produced in a welded vessel under such tests is considerable, the circumferential enlargement in at least one case being 10 per cent on a test drum designed for a working pressure of approximately 500 pounds per square inch, but which did not fail until an internal pressure of 2930 pounds per square inch had been applied. In predicting the performance of welded pressure vessels which may be subjected to variable pressure or even cycles of pressure over a long service period, the breathing tests which were conducted on full-sized welded test drums and shells by The Babcock & Wilcox Company were of great interest and value.[2-3] One of these test drums was subjected to over two million applications of internal pressure at 1½ times the working pressure, based on a factor of safety of five, each application of pressure corresponding to a circumferential stress cycle across the welded joint of from zero to 16,500 pounds per square inch. The drum was subsequently subjected to approximately 30,000 cycles of pressure at twice the working pressure (stress cycle from zero to 22,000 pounds per square inch) without evidence of failure. It is of interest to note at the present time that the welded joints of this test drum which gave so excellent a performance under this severe fatigue or breathing test service, possessed a degree of porosity far in excess of that now permitted under present commercial radiographic standards for pressure vessel welds. Finally, it was necessary to develop suitable specifica-

tions and codes covering the design, construction and testing of the different types of welded vessels.

The historical development of fusion welded pressure vessels, including a discussion of the metallurgy and properties of welded joints, has been recorded in prior technical literature and need not be detailed in the present paper. The subject is more general and a brief description and discussion will be given of certain phases relating to design, materials, methods of manufacture and of testing, particularly with reference to present standards, developments and trends.

CLASSIFICATION AS TO DESIGN AND TEST REQUIREMENTS.

In all existing specifications and codes covering the construction of welded vessels, cognizance has been taken of the widely varying types with respect to dimensions, diameters and plate thicknesses, and of the varying degrees of severity of service operation. Two hazards, one a constructional hazard by reason of increased plate thickness involved in fabrication, and the second a service hazard, have therefore been considered in drawing up specification requirements as to design, fabrication and testing methods. The greater the amount of stored energy of the contents of the vessel in service, the greater is the potential danger, and the constructional and manufacturing features and testing procedures should logically be more exacting. Vessels have therefore been classified as to their intended use and constructional standards varied in accordance with this classification. The most exacting standard has been applied to steam boiler drums and other vessels forming parts of high pressure steam generating units. The same standard has been applied to unfired pressure vessels which may be used for any purpose and without limitation as to operating temperature and pressure. A number of lower standards of construction for other unfired pressure vessels exist, but each class is restricted to vessels operating at a definite maximum temperature and pressure. Maximum plate thicknesses which may be used in the construction of vessels under these lower standards are also imposed.

The various constructional standards differ as to types of joints permitted, number of welded test plates and number of test speci-

mens therefrom, minimum physical properties required on the various test specimens, and necessity for X-ray examination and stress relieving treatment of the welded joints. The permissible joint efficiency naturally varies with each constructional class, the maximum granted to date in any of the existing specifications being 95 per cent for a joint of the double Vee type which has been fully X-rayed and stress relieved (API-ASME Code). Some differences exist between the various specifications as to detailed requirements for similar types of vessels, this being largely due to the different factors of safety used as bases of design by the various codes and to the different service conditions and rigidity of inspection during service of the various industries. Space does not permit even a brief discussion of the differences between the various constructional standards of the four or five major specifications and codes.

The following discussion as to manufacture of welded pressure vessels is largely confined to those of the highest class, which require the most exacting testing including complete X-ray examination, and which are covered by rigid restrictions as to design and fabrication including thermal stress relief. An example of this class of vessel is shown in Figure 1. Although pressure vessels of this class are not necessarily the most important, being numerically small in comparison with the total number of welded pressure vessels and tanks produced annually, they represent the optimum in weld quality and are used under the most severe service conditions in important fields of application, which would have remained closed to welded construction had not their safety been established by X-ray and thermal stress relief requirements.

MATERIAL.

At the time of adoption of fusion-welded pressure vessel specifications, the parent metal for shell construction was confined to relatively low carbon steel plates of 55,000 or 60,000 pounds per square inch minimum tensile strength of flange or firebox quality, plates of this general tensility having long been standard for riveted construction.

Within the past three years the extended use of higher operating pressures, especially in power boilers, requiring proportionately

heavier plates of the usual tensility with attendant difficulties in fabricating the heavy plate, brought a demand for a high tensile plate. This was conveniently obtained by slight modification in the usual plain carbon steel analysis, a slight increase in the carbon, manganese and silicon contents to 0.35, 0.90 and 0.25 per cent maximum, respectively, permitting a minimum tensile strength of 70,000 pounds per square inch without introducing alloying elements, which would materially decrease the weldability of the steel. Two specifications for two ranges in plate thickness below and above 2 inches and for two minimum tensile strengths of 65,000 and 70,000 pounds per square inch, have been issued by the American Society for Testing Materials [4] and adopted by a number of the pressure vessel construction codes. Their introduction resulted in a weight reduction of approximately 20 per cent, which represents a considerable advantage in thick vessels required in high pressure design. A further economy in fabrication is effected since a correspondingly smaller amount of weld metal is required and the proportionately thinner walls also permit more rapid X-ray exposure of the welds and greater ease of interpretation of radiographs.

Certain changes in welding technique from that established for the lower tensile steels were, of course, necessary. A weld metal, possessing a minimum tensile strength of 70,000 pounds per square inch after thermal stress relief at 1150 degrees F. and with the minimum specification requirement of 20 per cent elongation in 2 inches, had to be developed, necessitating a change in electrode chemistry, usually the addition of a slight amount of molybdenum. Greater precaution in certain phases of fabrication must be observed, the high tensile steels possessing a slightly greater tendency to cracking during forming and welding. This has led to a majority opinion among welding engineers that pressure vessels constructed of these steels should be both X-rayed and stress relieved even for the thinner vessels which do not require these precautions when constructed of lower tensile plate. These high tensile plates have been used in the fabrication of the bulk of boiler drums and other vessels in the past two years. Prior to their adoption for pressure vessels, over 50,000 tons of steel plates of practically identical chemical and physical properties were successfully

welded in thicknesses up to 2⅞ inches in the construction of the large 30-foot diameter penstock pipe sections of the Boulder Dam project (Figure 2).

As previously stated, drums up to 5 inches thick have been fusion welded. Such heavy plates are finished on the plate mills at high temperatures well above their critical temperature range, resulting in a coarse grained condition. While this condition is unrelated to any welding problem, such heavy plates above 2 inches thick, entering into welded pressure vessel construction, are normalized, the resulting fine grained structure producing a more uniform and higher yield strength and tensile strength in the plate material with accompanying increases in ductility and toughness.

With a maximum carbon content of 0.35 per cent in the parent metal, no undue and excessive difficulties in welding have been encountered attributable to inferior steel plate quality. Laminations in plates have occasionally been troublesome due to their tendency to open on welding. Slag inclusions in more than normal amount may, if of the sulphide type and critically located along the plate joint edges, occasionally tend to slight porosity in the weld metal near the fusion zone or to slight microscopic fissuring in the fusion zone between plate and weld. The record, on the whole, has, however, been excellent for the uniform weldability of American carbon steel plates of flange and firebox quality in a field of welded construction where the welds are subjected to minute inspection.

While the various low alloy high tensile steels have been extensively applied in the past three years to many welded structures, particularly in the transportation field where saving in weight is vital, their use in pressure vessel construction has been extremely limited largely by reason of their relatively high cost and by reason of present limitations in the pressure vessel codes. A number of ½ per cent molybdenum-bearing steel vessels have recently been constructed, this steel being used to advantage for vessels operating at high temperature by virtue of its superior creep resistance at temperatures above 750 degrees F. A considerable tonnage of 2½ per cent nickel steel plates has been employed in the past few years in welded vessels for service in low temperature processing in the oil and chemical industries, this alloy steel in both weld and base metal retaining its notch toughness at sub-zero temperatures, at

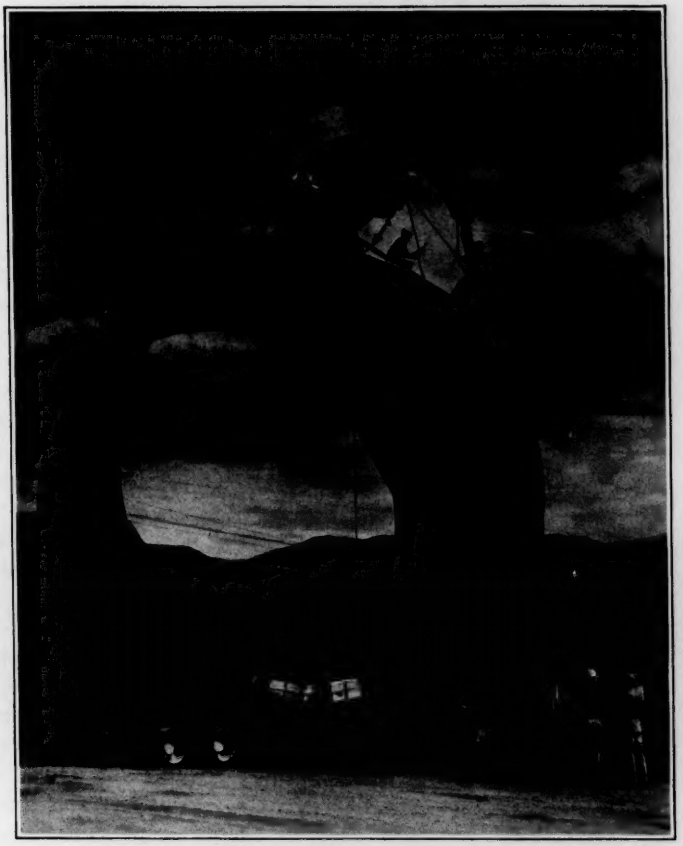


FIGURE 2.—BRANCH CONNECTION SECTION OF BOULDER DAM PENSTOCK, SHOWING STREAM LINED OPENING IN 30 FEET DIAMETER SECTION FOR ATTACHMENT OF 13 FEET DIAMETER LATERAL PIPE.

which temperatures the plain carbon steels are subject to notch sensitivity.[5] With suitable precautions these low alloy high strength steels may be successfully welded and their extended use in X-rayed and stress relieved vessels may be anticipated for special service conditions where one or more of their special properties is necessary or desirable. Official approval of their use will undoubtedly be forthcoming when the demand is sufficiently great.

Greater difficulty is experienced in the welding of alloy steels, containing sufficient alloying elements to produce a hard martensitic condition on cooling from welding temperatures. In spite of the air or weld hardening characteristics of the 4 to 6 per cent chromium-½ per cent molybdenum steel, which is typical of this group, this alloy steel has been successfully used for welded superheater drums and high temperature heat exchangers, where its superior corrosion, oxidation and creep resistance is of material advantage. Special temperature control during welding is necessary to avoid weld cracking (Figure 11). The welded structure may be subjected to softening heat treatment, producing welds of excellent toughness and ductility.[6] Until its weld hardening characteristics are eliminated or minimized by suitable modification of its chemistry as by columbium additions, its use in the welded pressure vessel field, however, will be necessarily restricted to small drums which can be conveniently preheated and maintained hot during welding operations.

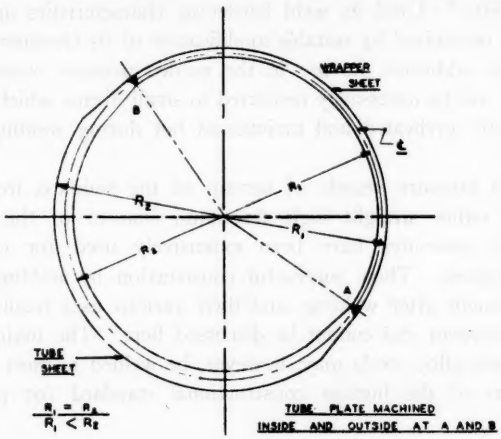
Welded pressure vessels of certain of the stainless irons and steels of either straight high chromium iron or of the nickel-chromium austenites have been extensively used for chemical process vessels. Their successful construction by welding, their heat treatment after welding, and their various uses require individual treatment and cannot be discussed here. The majority of the stainless alloy steels may, however, be welded to meet the requirements of the highest constructional standard for pressure vessels.[6]

PREPARATION FOR WELDING.

The plates as received from the steel mill are slightly larger than the theoretical dimensions to permit planing to accurate design sizes and to remove any mill shearing or torch cutting effects at the

edges. The plates are first carefully inspected to assure freedom from surface defects and laminations, sandblasting of the plate surfaces for removal of mill scale prior to inspection being necessary in some cases. Planing of the plate edges to the form of the desired joint wall may then be done, although it may be postponed until after the forming operation, if the drums involved can be conveniently handled on the planers. The plates are bent to cylindrical contour by either hot or cold bending or rolling, the choice depending upon the length, diameter and thickness of shell section being fabricated. Either single plate or multiple plate construction involving two or more longitudinal plate elements per shell section may be employed. The formed plates are then tack welded together, forming the longitudinal joints.

In boiler drums having a thick tube sheet and a thinner wrapper sheet, the two plates may be formed to the same mean diameter, and cross-sectional symmetry thus obtained between the plates of unequal thickness (Figure 3). Both surfaces of the heavier plate edges are tapered to eliminate sudden changes in section and pro-



CROSS SECTION OF DRUM

FIGURE 3.—CROSS SECTION OF BOILER DRUM OF TWO PLATE CONSTRUCTION, INVOLVING THIN WRAPPER SHEET AND THICK TUBE SHEET.

vide for more uniform stress distribution across the joint. The heavier plate edges are similarly tapered at the ends of the shell to the thickness of the heads, which are later welded on. Such boiler drum construction provides for economy in weight and results in a thinner weld, which is of material importance in the construction of extremely high pressure units by reason of greater ease of welding and of X-ray examination of the thinner joints.

This design with two plates of unequal thickness is, of course, impossible with riveted construction and represents a further advantage of fusion welded fabrication. This greater flexibility in design, permissible by fusion welding, has already been referred to, a most striking example being the Boulder Dam branch connection section (Figure 2), where the connection between a 13-foot diameter pipe entering the large 30-foot diameter main penstock has been attained by curved sections joined by butt welds, resulting in the optimum stress distribution within this critical section. Similar welded design for normal size nozzles and other outlets on pressure vessels will undoubtedly be more widely used.

WELDING AND FABRICATION PROCEDURE—GENERAL.

The formed and tack welded shell plates are welded and after dressing of the weld surfaces may be subjected to radiographic inspection, although this generally follows the completion of welding operations. The ends of the welded shell section are then machined for the joint wall of the circumferential welds. The circumferential welds attaching adjacent shell sections or heads are then made. Prior to welding on of the heads, any nozzles, manways, bosses or other reinforcements have been welded on the heads to permit horizontal welding of these parts. Nozzles and other attachments are welded to the shell of the drum or vessel, generally after the completion of the main longitudinal and circumferential joints. These attachments may be single forgings or of "built up" welded plates. After suitable dressing by chipping and grinding of the weld surfaces, X-ray examination of the main welds is made or completed. Unacceptable defects are removed and the defective portions repaired and reX-rayed, and the procedure repeated if necessary. The vessel is then stress relieved and subjected to hydrostatic acceptance test and final inspection.

WELD METAL DEPOSITION.

Metal arc welding using covered electrodes is in general use in preference to other welding processes for vessels of the highest class, although a limited number of such vessels have been welded employing gas or acetylene welding, and recent developments in automatic mechanisms for this type of welding may permit extended use in this field. The electrodes employed in the present conventional method are of either the cellulosic base or mineral base covering types, with preference in general practice to the latter type. The protection of the molten weld metal by both of these types of coverings is now generally understood and recognized as a necessity for the production of ductile weld metal. The electrodes are of the usual low carbon steel chemistry unless high tensile plate or other alloy steels are involved, where alloy steel electrodes to produce the required chemical or physical properties approximating those of the base metal are required.

The electrodes are generally of ¼ inch diameter and are deposited at welding amperages of between 350 and 400. A.C. welding current is preferably used by most fabricators. The weld metal is built up in the grooves by the deposition of successive layers approximately 1/8 to 3/16 inch thick, requiring about 8 to 10 weld layers per inch of joint thickness. This multiple layer method of deposition results in the bulk of the weld metal being fine grained, the heat from each bead on deposition subjecting the previous bead to a grain refining thermal cycle. Each bead or layer is freed from overlying slag, resulting from the fusion of the electrode covering ingredients, and thoroughly cleaned and peened prior to deposition of the subsequent weld layer. Peening does not materially affect the properties of the resultant weld metal after thermal stress relieving treatment, and is only considered advisable and necessary as a preventive of cracking and of distortion during welding due to the accumulation of welding stresses in the vicinity of the welds.

The weld metal is deposited for one or two layers above the surfaces of the adjoined plates, this superposed weld metal being later removed by chipping and grinding. This removal of the excess weld metal with a resultant flush weld or one with a slightly convex surface of the same approximate thickness as the plates

is accomplished for several reasons. The last bead deposited, not being subjected to a grain refining temperature, possesses a columnar structure, characteristic of single layer welds in the "as deposited" condition. This columnar structure is generally considered undesirable, being slightly inferior in toughness to the grain refined portion of a weld. Dressing of the weld surface eliminates any irregularities along the weld layer edges, which might produce localized stress concentrations, and the removal of such surface imperfections allows greater simplicity in radiographic interpretation.

The main longitudinal and circumferential joints are of the double butt type, "U" shaped grooves being generally favored for plates above ½ inch thick. Backing up strips are positioned along the junction of the projecting lips at the bottom of the U-groove, these lips being of a thickness and separated sufficiently to permit fusion of the first bead deposited in the groove through the lips and into the backing up strip. After the groove has been filled in from the outside, this strip is removed, any zones of incomplete fusion along the bottom of the joint on the inside surface removed by chipping, and one or two weld beads deposited. The bottom surface of the weld is then dressed by chipping and grinding in the same manner as for the outside weld surface. Variations from this procedure with respect to backing up strip practice may of course be used to advantage.

Some of the fabricators deposit the weld metal in the grooves of the main joints from automatic electrode feeding devices, which introduce the welding current into the electrode and feed the electrode downward by a set of driving rolls at a rate to compensate for the melting of the electrode at the arc. The driving rolls are actuated by a variable speed motor controlled by relays responsive to slight changes in the arc voltage, so that an arc of uniform length may be maintained. This electrode feeding device is mounted on a travel carriage which may be made to travel at any predetermined rate along a track paralleling the drum or shell and mounted on support stands above and behind the work. In the case of longitudinal joints the drum or shell remains stationary and the arc is traveled along the joint in successive passes. In the case of circumferential joints the arc (and welding head) is held stationary and the vessel is rotated at the desired speed on

drum turners. Since covered electrodes of long length or in coil form have been developed for automatic welding, deposition may proceed continuously without interruption or stoppage of the arc for a complete weld layer.

Other welded pressure vessel manufacturers employ manual welding for the deposition of the weld metal in the main joints and some controversy has naturally arisen as to the relative merits of manual and automatic welding in this application. Good electric arc welding is accomplished when the electrode is directed along the joint to be welded in a definite direction and at a predetermined speed, using predetermined welding current characteristics for the particular type of electrode used. The welding joint used must, of course, be properly prepared, this being variably designed to suit the peculiarities of a given job. The arc length must be kept constant within certain limits to assure the deposition of good weld metal, this being the most important variable in the deposition. These requirements may be met by either hand or machine welding. In manual welding the operator moves and directs the electrode and attempts to control its arc length as uniformly as possible, producing weld metal of a quality according to the degree of his experience and skill attained. The conditions may also be met by a well designed automatic welding machine which will automatically direct and move the electrode and maintain a constant arc length at predetermined settings. These functions may be varied, if desirable, by the operator during deposition by suitable adjusting mechanisms on the machine.

Since it is difficult to design a mechanism for irregular travel direction for automatic welding, manual welding is used to better advantage than automatic welding in the welding of irregular joints since the operator may more quickly change the direction of the electrode travel. It is also used for jobs where the quantity involved does not justify the expense of an automatic welding machine set-up. For straight line joints of long length and regular shape, such as the main longitudinal and circumferential joints of pressure vessels, automatic deposition is generally considered superior to manual welding. A constant arc length is maintained independent of any effort on the part of the operator, permitting him to concentrate his control only on the positioning and direction of the arc, whereas in manual welding considerable fatigue to

the operator is experienced by the necessity of feeding the electrode at a uniform rate to maintain a uniformly short arc. The question of operator fatigue is of considerable importance in relation to weld metal quality, particularly in the production of pressure vessel welds involving the deposition of large quantities of weld metal. In addition to the greater uniformity of arc length attainable independently of the operator, automatic welding possesses a further advantage in that welding is practically continuous without starting and stopping of the arc as in the case of manual welding where relatively short lengths of electrodes are used. Good or bad welds may, of course, be obtained by either method. The efficiency of machine welding is naturally dependent upon the perfection of the mechanical and electrical controls of the welding head, but experience has shown that with well designed automatic welding equipment the welds produced in the main joints of pressure vessels are of superior quality, requiring a minimum removal of defects and repair welding after X-ray examination.

TEST PLATES.

On all pressure vessel welding only qualified operators are used who have successfully welded test plates under conditions simulating as closely as possible the conditions encountered in the various welding operations of pressure vessel construction. The qualification test plates, specimens and requirements vary widely for the different welded vessel construction codes and specifications, and considerable unnecessary confusion now exists for this reason. An effort at simplification and uniformity of welding operator qualification tests is now being made, which will be of material benefit to the fabricator employing the same operators for the welding of vessels under different construction codes. For certain classes of construction no test plates are required beyond the periodic qualification tests, but for vessels of the highest constructional standard at least one welded test plate is required for each vessel produced, and in some specifications a test plate representing each longitudinal joint is required.

The test plate or test plates are attached to the ends of the longitudinal grooves and are welded simultaneously with these joints, so that sample welds are as representative as possible of the welded joints of the parent vessel. (Figure 4.) After com-

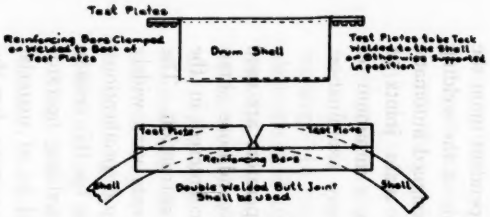

Test Plates
Reinforcing Bars Clamped or Welded to Back of Test Plates
Drum Shell
Test Plates to be Tack Welded to the Shell or Otherwise Supported in position
Test Plate
Test Plate
Reinforcing Bars
Shell
Shell
Double Welded Butt Joint Shall be used

Fig. U-9

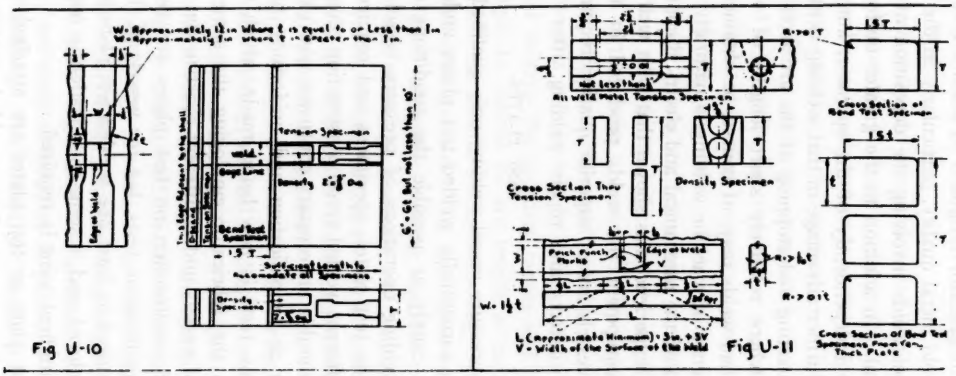


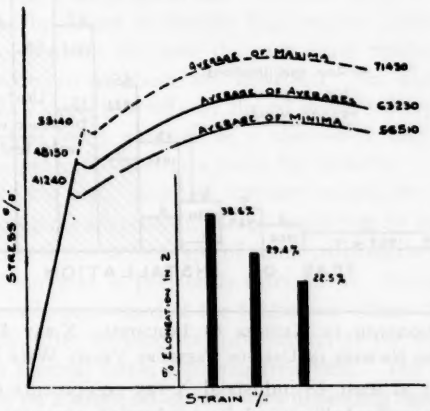
Fig U-10 Fig U-11

BOILER CODE REQUIREMENTS FOR CLASS I TEST PIECES

FIGURE 4.—TEST PLATES ATTACHED TO LONGITUDINAL JOINT OF PRESSURE VESSEL AND TEST SPECIMENS CUT FROM TEST PLATES AS REQUIRED BY SPECIFICATION.

pletion of the longitudinal seams the welded test plates are removed, stress relieved under the same thermal treatment as is later given to the completed vessel, and specimens of various types cut and machined for testing. The various specifications generally require the following specimens: (1) all weld metal tension test; (2) transverse tension test; (3) transverse bend test; and (4) all weld metal density specimens; while some of the more rigid specifications require, additionally, notched bar impact specimens of the weld metal, fusion zone between weld and parent plate, and affected zone of plate material.

Production control test plates of this type have been made to the number of approximately 10,000 and few specimens, representing a mere fraction of 1 per cent, have failed to meet the rigid requirements for welds of the construction codes. The uniformly excellent tensile properties of the weld metal on these may be best indicated by the data of Figure 5, representing the average physical properties of weld metal (for 55,000 pounds per square inch minimum tensile strength plate) as determined by thousands of 0.505 inch tensile bars produced and tested by five welded pressure vessel fabricators.[7]



Average Physical Properties of Carbon Steel Weld Metal as Determined by Thousands of 0.505 Tensile Bars Produced and Tested by Five Class I Welding Fabricators in the United States

FIGURE 5.—AVERAGE TENSILE PROPERTIES OF THOUSANDS OF SPECIMENS OF WELD METAL, PRODUCED FOR PRESSURE VESSELS UNDER HIGHEST CONSTRUCTIONAL STANDARD.

X-RAY EXAMINATION.

In the majority of the welded pressure vessel codes non-destructive testing by the radiographic method was made mandatory for the higher pressure boiler drums and vessels, and since the adoption of these specifications a large number of welded boiler drums, pressure vessels for various purposes, and welded steel penstocks have been fabricated and installed in service, the main joints of which have been subjected to X-ray inspection. The experience gained in this method of testing welded joints has therefore been extensive and, while limitations and defects of the method have been disclosed, important improvements in technique and apparatus have been developed.

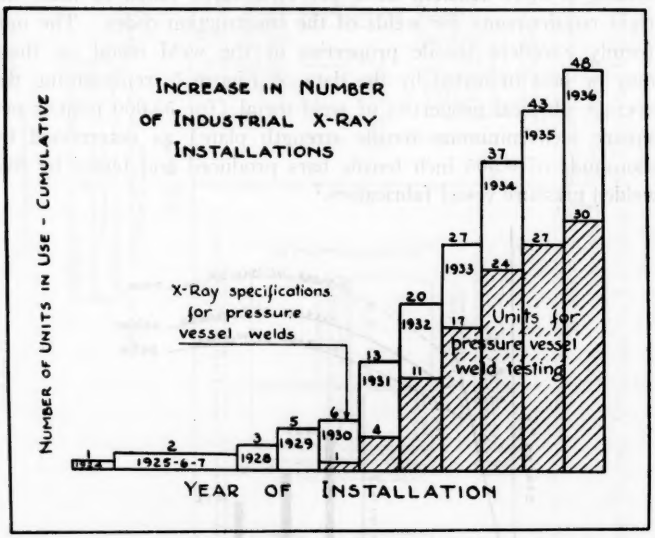


FIGURE 6.—INCREASE IN NUMBER OF INDUSTRIAL X-RAY INSTALLATIONS, SHOWING NUMBER IN USE FOR PRESSURE VESSEL WELD TESTING.

There are at least 48 industrial X-ray equipments in operation, 30 of these units being used in production pressure vessel weld examination by 22 different boiler and pressure vessel manufacturers (Figure 6). Data obtained from these manufacturers show that approximately 7,000 boiler drums and pressure vessels have

been fabricated, representing about 850,000 linear feet of welded joints of thicknesses from ¼-inch to 5 inches which have been examined by the X-ray method. The above total footage of radiographed pressure vessel welds includes the welds of three large hydraulic power penstock piping systems, the most notable being the large 30-foot diameter pipes of the Boulder Dam project already referred to, which alone required approximately 270,000 feet of X-ray film for weld examination. The X-ray equipments in use for weld examination differ considerably in their capacity and in their mechanical flexibility by which the X-ray beam may be directed on the welded joints. Starting with a maximum operating voltage of 200 kilovolts at the inception of welded vessel specifications, X-ray equipments have been developed during the past seven years, until today several units of 400 kilovolts capacity are in production use (Figure 7) and a 500 kilovolt unit has recently been announced. Mechanical flexibility of the equipments has been maintained or even improved in the newer high voltage units. (Figure 8 shows the most flexible type of equipment in use in the field in the examination of large diameter hydraulic power piping system. This equipment consists of a tube mounted in a shock-proof and ray-proof casing connected to a power plant by means of flexible high voltage cables, available in lengths up to about 125 feet, the tube being capable of operation at a maximum of about 220 kilovolts. The higher voltage units (Figure 7) are generally of the oil-immersed type, the tube and power plant being mounted in a case which may be rotated on trunnions and supported on a truck for mobility.

Fortunately the main joints of pressure vessels are of the butt type which are most adaptable to X-ray inspection by reason of the uniform thickness across this type of joint, particularly after dressing the weld surfaces as previously referred to. X-ray inspection of these joints is performed at the fabrication stages already indicated; namely, after welding and preparation of the weld surfaces and prior to thermal stress relieving treatment. The intervals of weld exposed on a single set-up will vary depending upon the thickness of the drums and the capacity of available X-ray equipment, but exposure lengths are generally about 9 inches for circumferential joints and 15 inches for longitudinal joints. The X-ray film

placed in a suitable cassette is positioned close to and along the joint and the X-ray beam directed through the weld from the opposite side of the weld (Figure 9).

Defects which occur in welds are slag inclusions, porosity, incomplete fusion, unfused zones and cracks, the most common of these being entrapped slag and porosity. The entrapped slag usually extends parallel to the wall of the joint (Figure 12), a small elongated slag body being considered acceptable provided it is limited in length to less than one-third of the weld thickness. A small amount of porosity is permitted, Figure 10 showing the maximum amount of porosity considered acceptable under the most recent requirements of the various specifications. A few years ago it would have been considered impossible to produce under production conditions welds which would comply on the whole with a rigid standard such as this, and the increase in the rigidity of radiographic specifications with respect to maximum permissible porosity indicates the part which X-ray examination has played in the improvement of weld quality. Major cracks are readily detectable by the X-ray method, Figure 13 showing a radiograph of a cracked weld 3⅞ inches thick. Small zones of incomplete fusion are somewhat more difficult to detect. Incomplete fusion is, however, generally accompanied by entrapped slag or by blowholes (Figure 14) and are removed under existing requirements.

Unacceptable defects are removed generally by chipping, the defective portions being repaired and reX-rayed prior to thermal stress relief. In the case of thick welds it is of advantage to know the depth of the defect from the surface so as to determine from which surface chipping should be done, thus saving the cost of excessive chipping and repair welding. The depth of the defect may be determined by stereoscopic illumination of two films or by double exposure of the defective portion from two different angles. In the latter method the displacement of the image between the two exposures is proportional to its distance from the film side of the weld.

Scattered radiation in the examination of heavy welds above 2½ inches thick may be sufficiently great to obscure the direct image of the weld condition, offering considerable difficulty in proper interpretation of the X-ray negatives. Industrial grids for

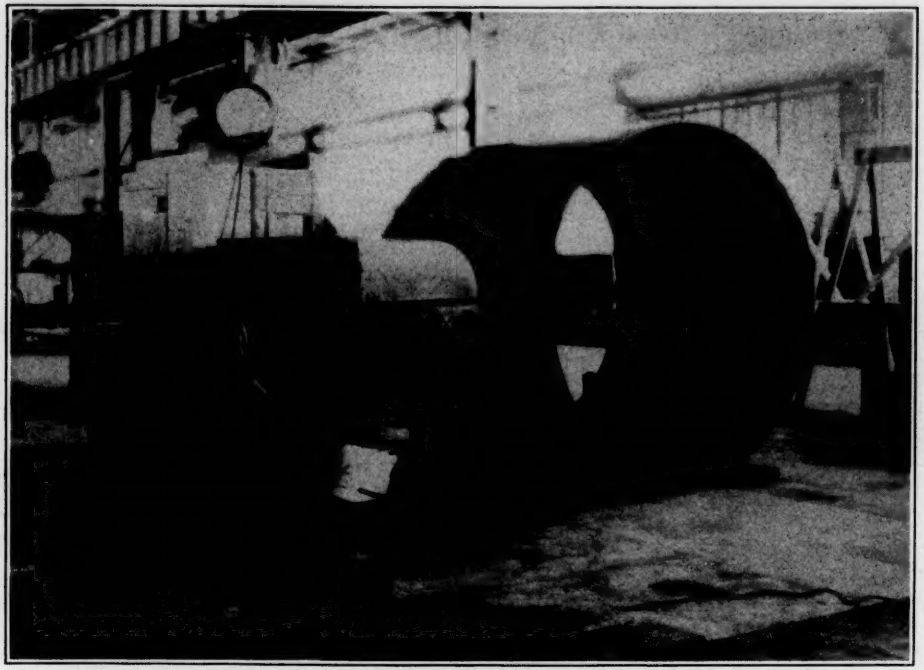


FIGURE 7.—OIL IMMERSED HIGH VOLTAGE UNIT (400 KV.) FOR HEAVY WALLED PRESSURE VESSEL WELD TESTING.

FIGURE 8.—X-RAY UNIT OF MAXIMUM FLEXIBILITY, 220 KV. CAPACITY. TUBE CONNECTED TO POWER PLANT BY LONG FLEXIBLE CABLES. IN USE UNDER FIELD CONDITIONS FOR EXAMINATION OF LARGE DIAMETER PENSTOCK PIPE.

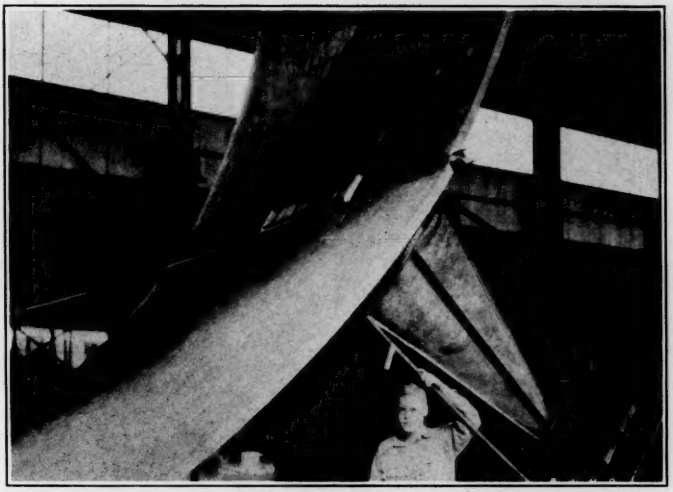


FIGURE 9.—CASSETTE CONTAINING X-RAY FILM PLACED IN POSITION BEHIND WELDS FOR X-RAY EXPOSURE.

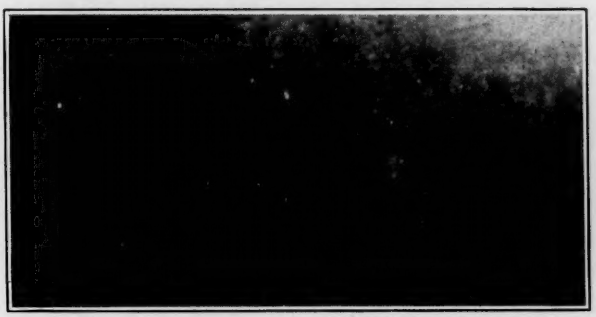


FIGURE 10.—RADIOGRAPH SHOWING DEGREE OF POROSITY, CONSIDERED MAXIMUM ACCEPTABLE UNDER PRESENT SPECIFICATION REQUIREMENTS.

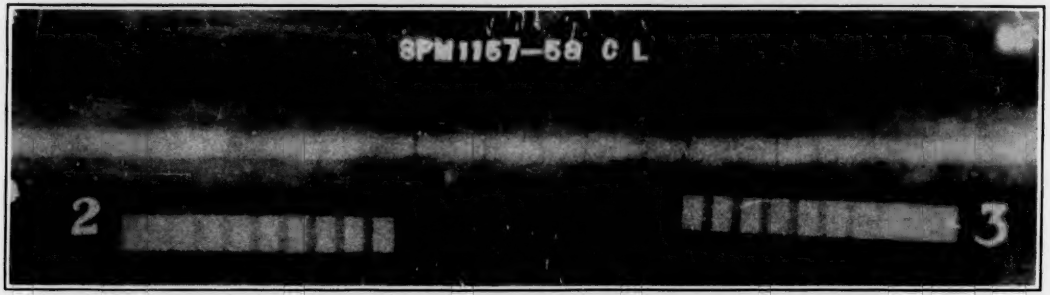


FIGURE 11.—RADIOGRAPH OF WELD ON 4–6 PER CENT CHROMIUM—½ PER CENT MOLYBDENUM MATERIAL, SHOWING TRANSVERSE CRACKS BY REASON OF LACK OF PREHEATING PRIOR TO WELDING.

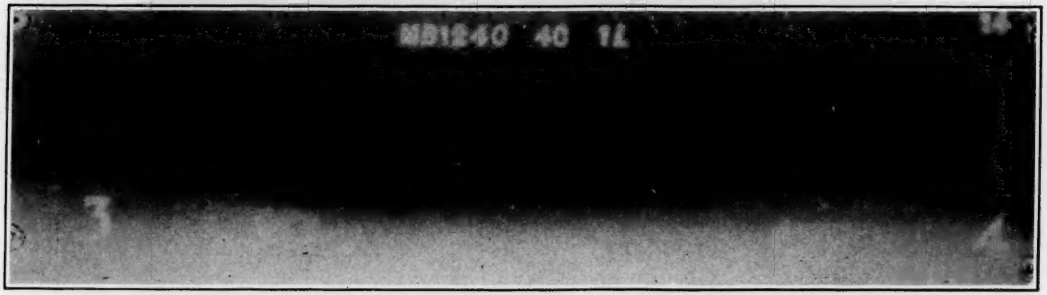


FIGURE 12.—RADIOGRAPH SHOWING ELONGATED SLAG ENTRAPPED IN WELD.

FIGURE 13.—RADIOGRAPH SHOWING LONGITUDINAL CRACK IN WELD 3⅞ INCHES THICK.

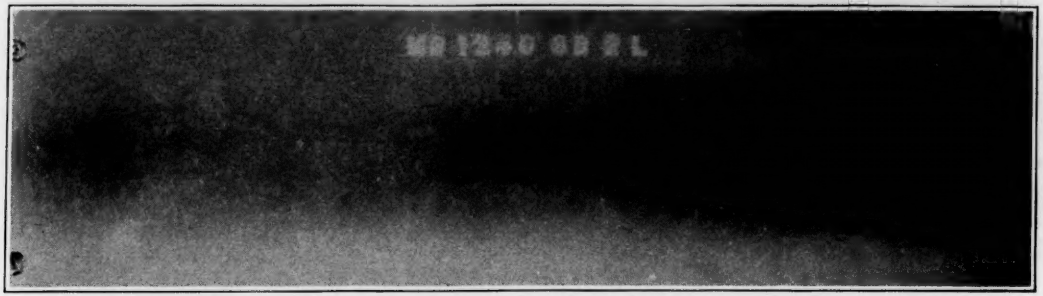


FIGURE 14.—RADIOGRAPH SHOWING INCOMPLETE FUSION IN WELD.

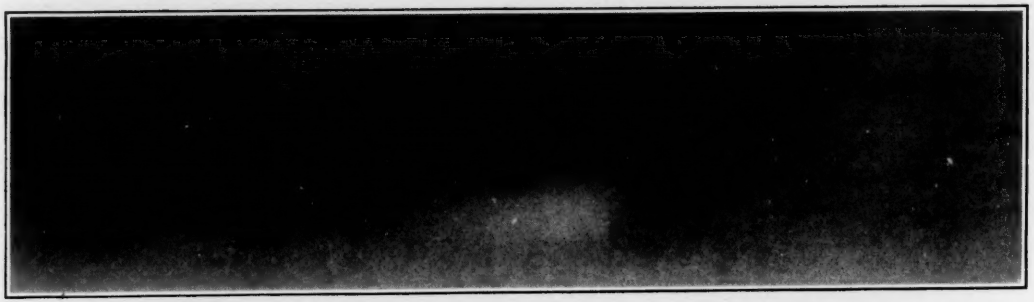


FIGURE 15A.—RADIOGRAPH OF 5 INCHES THICK STEEL BLOCK WITH HOLES DRILLED IN EDGES AND SURFACES. EXPOSURE MADE WITHOUT GRID.

FIGURE 15B.—AS ABOVE BUT WITH EXPOSURE MADE WITH MOVABLE GRID.

the elimination or reduction of this scattered radiation effect have recently been produced. Examples of the use of such a grid in eliminating scattered radiation on the exposure of a 5-inch thick plate with holes of various sizes drilled in the plate surfaces are presented in Figures 15A and 15B. The improvement in quality of image is evident.

It is generally held that X-ray examination of pressure vessel welds is desirable and that the additional cost is justified. Its application to weld testing has been a major factor in the acceptance of welded pressure vessels, in establishing confidence in their safety, and in extending the field of application of weld construction.

STRESS RELIEF.

In any welding operation high stresses are produced within the structure by reason of the widely varying temperatures co-existent at different portions of the structure resulting from the localized application of extremely high temperatures. The magnitude of the resultant residual stresses have been measured by a number of different methods, all methods showing that residual welding stresses are invariably present up to or beyond yield point value. For example, Figure 16 shows the distortion of a strain gauge pattern established on the surfaces of two plates, the distortion being measured after welding a flat circular plate 24 inches diameter by 1⅝ inches thick in center of 8 feet × 8 feet × 1⅝-inch thick border plate. Examination of this strain diagram will show that welding has resulted in plastic deformation beyond yield point value (.001 inch per inch strain) in the region of the weld, and that an elastically stressed condition exists even to the extreme border limits of the plate. While this particular experiment of residual welding stress measurements represents an extremely fixed or rigid joint condition, this condition is at least approached in the welding of many nozzle welds on pressure vessels.

Since these residual welding stresses necessarily detract from the safety of a welded structure of large magnitude, it has been considered necessary to remove them by subjecting the completely welded structure to a high temperature, at which the yield point of steel is reduced to a few thousands of pounds per square inch, thus permitting plastic adjustment of the structure with relief of residual

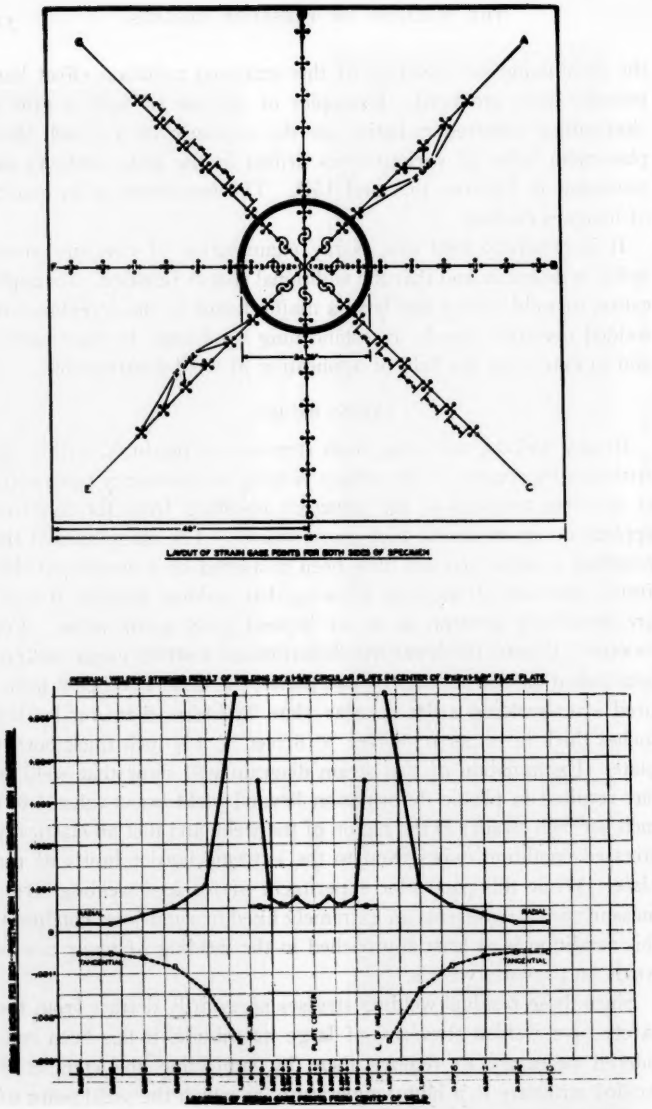


FIGURE 16.—SHOWING STRAIN GAUGE PATTERN ESTABLISHED ON PLATE SURFACES AND STRAIN DIAGRAM OBTAINED AS RESULT OF WELDING FLAT CIRCULAR PLATE 24 INCHES DIAMETER × 15/8 INCHES THICK IN CENTER OF LARGE 8 FEET × 8 FEET × 15/8 INCHES THICK BORDER PLATE.

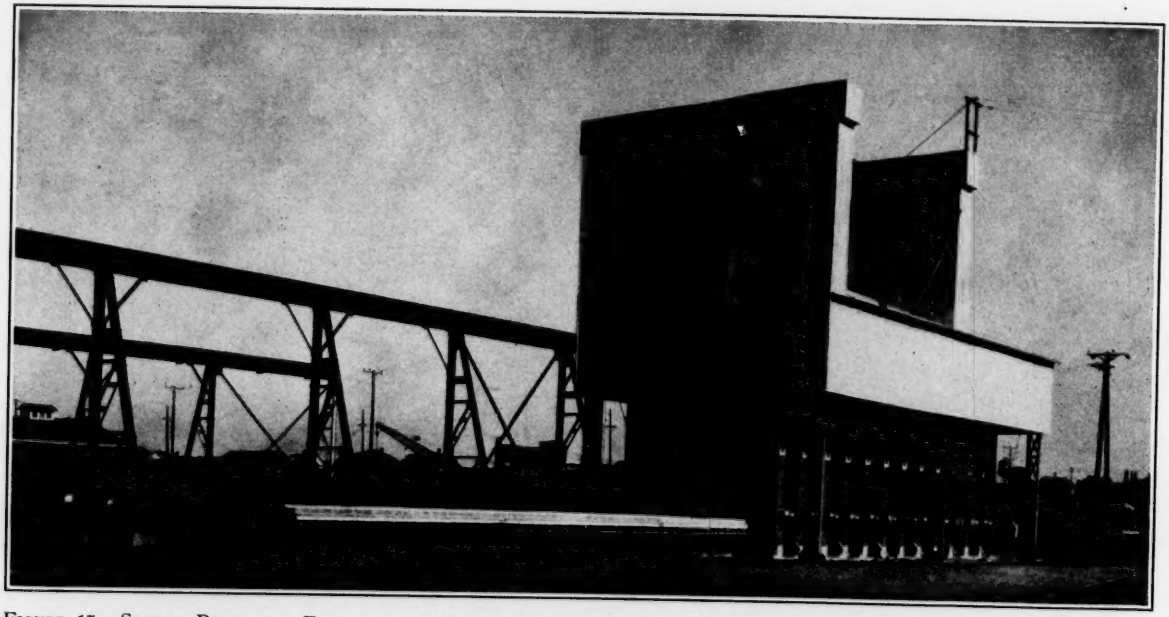


FIGURE 17.—STRESS RELIEVING FURNACE FOR LARGE WELDED PRESSURE VESSELS. INTERNAL DIMENSIONS 65 FEET LONG × 14½ FEET WIDE × 17½ FEET HIGH.

stresses. Such thermal stress relief has been specified in the various codes for the heavier walled higher pressure vessels and is accomplished by subjecting the entire vessel to a temperature in the range of 1100 to 1250 degrees F. for a period of one hour per inch of thickness, followed by furnace cooling. Furnaces of unusually large dimensions are required for the heat treatment of the larger pressure vessels, Figure 17 showing a stress relieving furnace of the car-bottom type 65 feet long by 14½ feet wide by 17½ feet high.

Relief of the residual welding stresses is accomplished at the temperature range indicated without appreciable change in the micro-structure and physical properties of both plate and weld metal.

HYDROSTATIC TESTING AND FINAL INSPECTION.

The vessels after stress relieving are hydrostatically tested to either 1½ or twice the design working pressure, the welds being hammered at intervals along their length while the vessel is under pressure.

Before or after the hydrostatic test the welds are given a final inspection by means of the Magnaflux test. This involves the magnetization of short intervals of the weld length, this being conveniently accomplished by passing the current from a 300 to 400 ampere D. C. welding machine in the region of the welds (Figure 18). This current establishes a magnetic field in a direction normal to the path of the welding current (Figure 19). Any small surface crack or discontinuity lying at an angle to the magnetic field is disclosed when a magnetic powder is sprinkled over the magnetized area. Small piles of powder clinging to the surface are indications of defects, these being best disclosed by gently blowing the powder after sprinkling but while the magnetic field is still intact. Two magnetic fields normal to each other are required for complete examination of a zone (Figure 19) since a small defect approximately parallel to the magnetic field may not be evidenced.

This magnetic method is an excellent supplement to the X-ray test for the detection of small surface cracks or zones of incomplete fusion which may exist in or adjacent to the weld, particularly on high tensile plate welds, and which are so small as to remain unde-

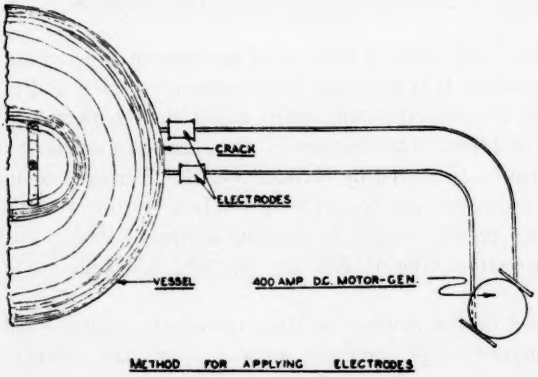
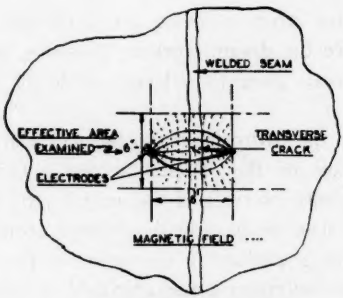


FIGURE 18.—METHOD OF APPLYING CURRENT FOR MAGNETIZATION OF WELD PORTION IN "MAGNAFLUX" TESTING.



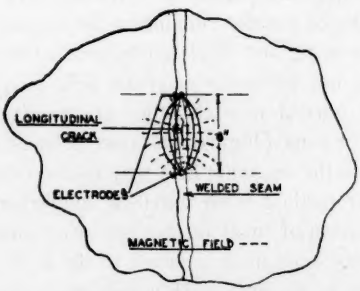


FIGURE 19.—SHOWING DIRECTION OF MAGNETIC FIELDS FOR DETECTION OF DEFECTS.

tected by the X-ray method on the heavier welds. The method, of course, may be applied at other stages of fabrication of the vessel.

CONCLUSIONS.

Within the space of a few years the construction methods in building pressure vessels have been completely changed, fusion welding as a method of jointing practically completely replacing the older methods of riveting or forge welding. This has been due to the many inherent advantages of welded pressure vessels, when the quality of the welds has been proven. Fortunately non-destructive testing by the radiographic method was made available as a practical and efficient method of establishing the quality of welds made under production conditions. The use of the X-ray method has undoubtedly been a major factor in establishing confidence in the safety of welded pressure vessels and in promoting their present extended use under official specifications and codes. Developments in welding and X-ray technique since the adoption of these specifications have permitted the construction by fusion welding of vessels with extremely heavy wall thicknesses up to 5 inches, fabricated of high tensile plate. Present developments will undoubtedly result in further improvements, probably in further fabrication economies and in the extension of fusion welded construction to higher pressure drums by the use of alloy steels of special mechanical and chemical properties.

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A DISCUSSION OF AUTOMATIC AND MANUAL ELECTRIC ARC WELDING.

By A. J. Moses.*

Through a decade of welding development Mr. Moses, in shop, laboratory, and committee-room, has definitely influenced the trend of the art. Accordingly, this discussion, in which he shows a strong preference for manual welding over automatic welding, should be given a careful reading, and due deliberation. After personal experience with both types of welding, he gives reasons for his preferences which are very clearly thought out. He pins his faith very largely on a proper processing of the welding rod, believing that with this feature of the technique properly cared for, the rest of the operation can be easily supervised into a successful job. As manual welding must be used in many applications where any automatic feature is impossible to apply, Mr. Moses' remarks are of particular importance in a consideration of the highest grade welds for high-test pressure vessels, and his argument will be interesting to all those specializing in this restricted field.

A discussion of this subject implies a study of the relative merits of the two methods. The field is so broad as to make necessary the confining of this study to a particular type of welding and to a specific class of work. Such classification will reveal with proper emphasis the factors that must be considered in weighing the merits of either method. These factors must be weighed in accordance with the requirements established by service in the particular field of application.

In important applications, certain prescribed tests are considered necessary with the idea that these tests will disclose whether or not the finished product will meet service requirements. A study of the merits of automatic and manual welding in a specific field entails a discussion of necessary tests and of what such tests have

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taught regarding proper welding procedures. From this a more intelligent analysis can be made of the adaptability of automatic control to the various factors involved. Conclusions may be drawn as to the degree of success obtainable in an endeavor to accomplish automatically a perfect technique, eliminating erratic results and the necessity of testing.

The demand for automatic operation is prompted by a desire for improvement in quality or economy, or both. Such operation appears to offer these advantages, implying, as it does, an elimination of the human element. In order to evaluate the merits of these claims, some definition must be given the vague term, "welding." It may be defined as the bonding of two or more metal parts into a homogeneous whole, "homogeneous" signifying that the integrated structure must possess uniform physical and chemical properties.

In many cases, such 100 per cent perfect welds are not necessary. In fact, frequently the physical and chemical properties of weld joints are of little importance. In that class of work, many successful applications of so-called "automatic operation" have been made, the primary objective permissibly being reduced cost. In this discussion, the specific study will be fusion welded pressure vessels of ordinary carbon steel. In the fabrication of pressure vessels, the material and construction requirements are most rigid, the main theme song being safety.

Fusion welding has supplanted riveting in this industry primarily because of the limitations of the latter in fabricating high pressure vessels. There is no need of further discussion of the superiority of ideal welding over riveting, but there is need of further discussion of some disadvantages inherent in the welding process. Every rivet joint presents a minimum calculable strength based on accurate testing of materials. On the other hand, an unproved weld joint presents only a question mark. Accumulated experience with welding has shown that deviations from average values are sometimes enormous.

In connection with welded pressure vessels, a good average is only a mild virtue. In this field, deductive logic forbade the use of welding pending the development of reliable test methods.

It has been found necessary to continually check the physical and chemical properties of base materials. In fusion welding, the deposited metal is manufactured during the welding operation. In the acceptance of important welding it is not likely that approved techniques or methods will supplant final individual testing. Correlated physical, chemical and micro tests of closely related samples, and X-ray examination of main weld seams have been developed and accepted as meeting the reliable test requirements. There is little hope of eliminating such testing in the near future, but rather there is a need of extending its use.

Thorough testing has been very instructive in the establishment of good welding procedures. The development of good techniques to meet the most rigid requirements has done much to improve the average quality of all fusion welding. The results obtained in the strictly controlled fields have been highly gratifying. However, it would be fallacious inductive reasoning to attribute to all welding such excellent properties or to assume that an automatically controlled technique would give unfailingly desirable results.

A satisfactory welding procedure must embrace preparation, actual welding, and subsequent treatment. The preparation has to do with the selection or processing of electrodes, the conditioning of the base material, and the arrangement for supplying the necessary electrical energy. The success of manual or automatic operation depends more on preparation than on the actual welding technique. The designation, manual or automatic, refers to the type of control exercised over the actual welding operation. Subsequent treatments, such as stress relieving, are of great importance in improving the quality of all weld joints, but have no bearing on a discussion of the relative merits of manual and automatic control.

Of major importance is the selection and processing of electrodes. A good weld rod will not insure a good weld joint, but does make such a result possible. The metal core and the coating of the electrode must be so related and controlled as to produce fusion weld metal of the desired chemical and physical properties. Generally, but not necessarily, chemical control of metallic elements is exercised through control of the chemical analysis of the metal core. If this metal core could be fused into weld joints without

damage, then no coating for the rods would be necessary. To prevent damage during the fusing, it has been found best to use slag coverings over the pool of liquid metal, the same as in open-hearth steel practice. The use of this slag and deoxidizing agents, which are incorporated in the electrode coating, leads to good sound weld metal. Also, since the electric arc is rather fickle, means of stabilizing this are introduced into the rod coating.

A good welding procedure must depend on the electrode for obtaining good clean deposited metal, free of gas porosity. It is true that some success can be obtained by skillful operators in keeping low the gas porosity, in welding with rods which are "off color." Also different results are obtained with such rods in welding with A.C. and D.C. current and in changing the polarity of the latter. But fundamentally the weld rod coating is responsible for such porosity. The control that can be exercised by the operator, manual or automatic, is as nothing compared to the control that can be built into the coating. This control can be exercised through a wide latitude such that gas free welds can be obtained from the same electrodes by either A.C. or D.C. welding, and by the use of either polarity in the latter.

In matching the physical properties of the base material, ductility is of major importance. Due to the progressive manner in which arc welding is accomplished, extreme temperature differences occur in and around such joints. These conditions lead to the most severe contraction stresses, the degree of which depends upon the rigidity of the structure. It has been found that in simple butt welds, of relatively thin plate, these residual stresses equal the elastic limit of the material. These enormous shrinkage stresses constitute a much more severe test of the weld joint than do subsequent testing and working stresses. In order to withstand such stressing without cracking, weld metal must have a very high degree of ductility. Also it must exhibit this property throughout the entire cooling range, so as to prevent cracking either in the "red" temperature zone or after the metal has cooled to room temperature.

The control of such necessary physical properties as ductility and strength resides more in the processing of the electrodes than in the actual welding technique. The latter is extremely important,

as a highly developed technique is needed to supplement excellent weld rods, in the accomplishment of "crack free" welds in the presence of extremely high contracting stresses.

Lack of fusion and slag inclusions are mainly controlled through the actual welding technique. However, proper processing of weld rods has a great influence in eliminating these types of defects. Good electrodes require very little skill in actual welding. Slag coverings of the correct fluidity maintain a full coverage of the pool of liquid metal, and at the same time this slag is easily eliminated from the metal bath. Control of the electric arc by stabilizing agents, and concentrically coated weld rods, the use of exothermic reactions and proper oxide reducers has accomplished a great deal in the way of eliminating "undercutting," slag inclusions, etc. With such electrodes it is easy to obtain smooth beads of weld metal with no indication of laps or seams at the edges. In fact, in weld grooves a fillet effect is obtained at the side walls which is the reverse of undercutting.

The preparation and conditioning of the base material is also highly important. It is probable that this factor has received less attention than any of the others and is responsible for a large number of defective joints. While proper preparation does not insure good weld joints, it makes the attainment of such a probability, provided other factors are under control. In the design and preparation of such joints for welding, major consideration must be given accessibility and visibility during the actual welding operation. Economy in the amount of deposited metal required is an important matter, but must give ground to the considerations mentioned above. Carried too far, such economy makes necessary a greater degree of control in the processing of electrodes and a greater degree of skill in the welding operation. On the other hand, a waste of deposited metal, while it may not result in a reduced quality of the joint, may result in objectionable distortions.

Electric arc welding might be likened to a painting operation. In obtaining a good painting job, several factors must be considered: First, a good grade of paint must be furnished; second, the surface to be painted must be prepared to receive the coating; third, a good paint brush or spray gun must be available; fourth, an intelligent workman must be secured and he must be given good visibility

and ready access to all surfaces to be coated. In obtaining a good welding job, the same considerations hold. The electrode with the electric current offers a fountain reservoir of good ready-mixed paint. The electric arc constitutes the brush or spray gun. The D.C. arc gives a soft bristle brush, while the A.C. arc furnishes a much stiffer one. There is a division of opinions as to which is the better brush; perhaps the former needs a few stiffer bristles in the central portion, and the latter some softer ones on the fringes. This improvement can be obtained for both in the coating of the electrodes, which, if properly done, will serve with either type of arc.

In addition to this mechanical aspect, electric arc welding presents certain chemical and electrical phases. For the most part, the chemical problems are taken care of in the coated electrode. Current density, striking voltage, arc voltage, arc length, welding machine characteristics, and what-not, are all important and tribute should be paid to the thought and improvements that have been rendered along these lines. But after all, welding is a mechanical, chemical and thermal process, and the electric current and electric arc are mere agents and subordinates in the attainment of desired results. This position is substantiated by the fact that desired results can easily be obtained by the use of almost obsolete electrical equipment.

The amperage to use is primarily a function of the thermal condition of the base material and liquid pool of weld metal. Of course, to meet varying conditions, the diameter and length of electrodes and the stability of weld rod coating must be such as to permit of rather wide variations. As an instance, ¼-inch diameter electrodes can be used conveniently and safely from 250 amperes to 375 amperes, depending upon requirements. The arc voltage required is that which is necessary to pull and maintain a steady arc from a properly coated electrode. Since there are probably innumerable combinations of coatings that will prove satisfactory, the arc voltage requirement is a function of the particular electrode and the particular instantaneous requirements; that is, whether a convergence of the arc is necessary because of a particular vulnerable spot, or whether a dispersion of the arc is permissible as under normal conditions.

As regards arc length, a great deal has been said and written. With bare electrodes it was considered necessary to maintain a short arc length. This was probably a correct view. With some coated electrodes being used today, a short arc will produce a porous weld. The arc length per se is not responsible for this. It has been demonstrated that desired chemical reactions can be arranged, regulated, accelerated, or retarded in the processing of electrodes, such that arc length variations within very liberal tolerances have no effect on quality of weld metal.

If the above factors have been weighed properly, it would seem an easy matter to obtain good well joints automatically. In fact, good weld metal can be deposited automatically with very little difficulty, as little is required of the actual welding operation in obtaining such results. The manufacture of deposited metal is accomplished in a very small space. This consists of the cooling pool of liquid metal, its slag coating, the welding arc and its surrounding atmosphere. In this small field of operations, truly automatic processes must be depended upon for the production of high quality deposited metal. As stated before, these processes must be planned beforehand, in the processing of the electrode, the conditioning of the receptive work material, and in making available the necessary electrical energy.

To be successful, these processes must function from start through the finish of an arcing period. Arc breakages should be of no moment and are of no importance, provided the thermal condition of the base material is not materially different at the time of re-arcing. What happens to the electrode above the arc zone, in the way of manipulations, has no bearing on weld metal quality. Some manipulation must be furnished in order that the process may proceed, but, with a good welder, all manipulation is a matter of reflex actions.

It is in the attainment of good fusion to the base materials and relatively smooth layers of deposited metal that the greatest skill is required on the part of the operator. With a skillful manual operator, all manipulation of the electrode pivots about the electric arc. With a good electrode, he has to pay very little heed to the length of arc or angle of electrode, being automatically guided in the manipulation of these by local conditions just ahead of and in

the pool of liquid metal and the behavior of the electric arc. To him, welding is a mechanical operation guided by a knowledge and recognition of normal and abnormal conditions in his small field of operation. This knowledge and recognition of details soon becomes subconscious and his conscious thoughts dwell on other subjects. The things that worry him most are too many abnormalities, discomforts, lack of visibility, and restrictions to his freedom of manipulation. Where these conditions are bad, welding is most fatiguing and "bobbles" are sure to occur. Tests are required to disclose these "bobbles" as well as those for which the welder is not responsible.

Automatic welding would be justified if for no other reason than to relieve operators of this fatigue. Unfortunately, automatic welding can not do the job where abnormal conditions prevail which cause excessive fatigue. In fact, the category of abnormalities actually increases with automatic welding, on account of its inflexibility and the natural imperfections of materials and preparations. Under severe conditions, conscientious workmen experience greater fatigue in operating an automatic machine than they do in welding manually. Under ideal conditions where automatic welding is applicable, hand welding is also extremely easy.

Reliable test requirements will divulge the seriousness of defects, whether the welding is done manually or automatically. The correction of these defects is generally expensive, therefore welding fabricators are continually striving for the "perfect welding technique," and in this struggle have given a great deal of attention to the automatic idea. So far, considerable progress has been made toward bringing up the standard of quality of such welding to that obtainable by expert manual operation. The automatic process has been applied with more or less success to the longitudinal and girth seams of a restricted class of pressure vessels such as boiler drums. But in this application quality has not proven superior to that obtained by manual control; neither has the expensive correction of defects been eliminated.

A full understanding of the best manual technique discloses the difficulties that will attend attempts at automatic control. The satisfactory transference to an automatic machine of all the func-

tions necessary to the procurement of excellent weld joints can be only partially obtained, and that in connection with the simplest type of weld seams. The word "automatic" in the sense of implying the elimination of the "human element" should not be applied to the electric arc welding process. The reasons for this are almost as numerous as the factors that affect the accomplishment of excellent quality weld seams. The control of the essential factors affecting the actual welding procedure has not yet been secured by any automatic methods. Furthermore, no method has been devised sufficiently flexible or elastic to contend with the many other variable factors connected with welding in general. The question of manual or automatic welding should be weighed in the light of which is more economical.

In this discussion no attempt has been made to go into all of the details of existing automatic controls. In many cases, such control has been attached to non-essential items; and in all cases some very essential factors have not been harnassed. The discussion has been limited to what is actually done in making a good weld and to the essential factors in procuring such. From this it has been left to the reader's judgment as to the difficulties that will be encountered in duplicating or bettering expert hand operation by automatic control, and as to the degree of success obtainable in such attempts.

FUSION WELDING.

By Bela Ronay.*

Mr. Ronay started his welding career in this country many years ago with the Thermit Welding Company, and few men with his technical education have lived their lives closer to the practical shop operations of all types of welding than he. In this article, he has assembled most of the known facts, and many of the more reasonable speculations which surround the formation and deposit of a molten metal drop in the electric arc method of welding. His discussion of apparatus, electrode covering, and technique is so complete, that it should serve as a useful manual to all those interested not only in the visible accomplishment, but in the reasons which underlie it.

Fusion welding of metals is used today in industry for practically an unlimited variety of fabrication. Its intelligent use simplifies many design problems, and results in better, lighter, and less expensive construction of both light and heavy materials.

Fusion welding is a method of uniting *physically* most ferrous and some non-ferrous metals by forming a bond developed *progressively* by means of a concentrated source of heat. Fusion welding may be performed either with or without the addition of extraneous metal to form the joint. There are several fusion welding procedures; namely, electric arc welding, the oxy-acetylene and oxy-hydrogen method; and the atomic hydrogen method belongs in this class when fusion welding is interpreted within the scope of the above given definition.

The following remarks are restricted to the metallic arc and the oxy-acetylene torch as the sources of the welding heat. The remarks are further confined to the production of a weld between parts by depositing additional material known as filler or weld metal.

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METALLIC ARC WELDING.

To produce a joint by arc welding, it is necessary that the following requirements be met:

(*a*) The gap between the members of the joint must be filled with dense weld metal.

(*b*) The weld metal must be thoroughly fused with the base metal. [(*a*) above requiring the weld metal to be dense automatically demands the uniform fusion between successive layers of weld metal.]

The material used in arc welding is applied in the shape of rods or wires known as electrodes. In order to comply with a fundamental requirement, the composition of the electrode is usually so chosen that the composition of the resultant filler metal is approximately the same as that of the base metal. To convert the electrode into weld metal, the electrode is melted by means of the electric arc. When the arc is struck the heat liberated raises the temperature of the base metal as well as that of the electrode. The mass of the base metal affected by the heat of the arc is many times greater than that of the electrode. Therefore, the tip of the electrode is heated to a higher degree than the surface area of the base metal.

In order to produce a satisfactory weld the current rate through the arc must be so regulated that the melting rate of the electrode will be proportional to that of the base metal. By "regulating the melting rate" of the electrode is meant restricting the current value to that maximum which permits the melting of the electrodes in drops. If the current rate is sufficiently high to melt the electrodes in a continuous stream, some of the fundamental requirements of properly welded joints cannot be satisfied.

When the current rate is so regulated that the dropwise melting of the electrode is accomplished, then the procedure of metal transfer through the arc is cyclic; first the "drop formation period" and then the "drop transfer period." The frequency of the periods varies with every type and brand electrode. This is one of the important features which makes the welding with one electrode an entirely different problem from welding with any other.

During the drop formation period, it may be assumed that there is no relative motion between the electrode and the work. The

heat of the arc is then concentrated on a small surface of the base metal. As the capacity of the latter is insufficient in most cases to transmit and dissipate the heat input at the rate it is received, a high degree of localized heat develops under the arc. The degree of heat developed then depends on the following:

(*a*) The heat conductivity of the base metal.
(*b*) The mass and mass distribution of the base metal.
(*c*) The actual length of the preheating period.

The first factor is responsible for the difficulties met in welding copper and other metals of high heat conductivity. The influence of the second factor is self-evident. The third factor gives the key to the successful design of all metallic welding electrodes. Each single drop must be liquid enough to possess a sufficiently low surface tension to conform to the contour of the melted or semi-molten base metal upon which it is deposited. The preheating time must be sufficiently long to cause the base metal to reach a molten state over a large enough area to accommodate the volume of the drop. When the volume of base metal preheated during the drop formation period is proportional to the volume of the latter, the deposit is prevented from becoming chilled quickly, the base and weld metals become fused to each other so that the bond between them is not a mechanical one as in a blacksmith's weld, but a physical alloying of the two metals.

The foregoing remarks have been confined to the beneficial effects of the preheating period of proper duration only. The period is too short when the drops are transferred before the corresponding volume of base metal is heated to the proper temperature. Consequently the drops become chilled immediately upon being deposited, causing a porous weld whose bond is apt to be of the mechanical type, and a high-crowned deposit which hinders the successful deposition of a proper second pass.

ELECTRODES.

There are three general types of electrodes used in welding fabrication; viz., bare wire metallic electrodes, coated, and covered electrodes (shielded arc). Let it be said here that as a general rule the bare wire electrode is now used only for "tacking," securing sections of base metal only temporarily until the sections can

be secured by better means; coated electrodes are used to some extent in structural fabrication.

In depositing bare wire and coated electrodes it is customary to take advantage of the fact that about 20 per cent more heat is generated at the positive pole than at the negative. Therefore, the larger mass of the work is made the positive pole of the welding arc. This is always referred to as *"straight polarity."*

For a reason similar to the one requiring bare electrodes to be deposited with straight polarity (work positive), covered electrodes are nearly always deposited with *"reversed polarity"* (work negative). This is done because more heat is generated at the positive pole (electrode) in order that the heavy coating may be melted.

In the course of welding with bare ferrous electrodes the drop frequency is relatively low, ranging from 12 to 50 drops per second for a 5/32-inch diameter electrode. The lower the carbon content, the lower is the drop frequency while the formation period is correspondingly long also. The volume per drop is the largest for electrodes of the maximum .06 per cent carbon range. When the drops are large, the transfer periods are sluggish. The long preheating periods expose the nascent metal too long to atmospheric contamination and the sluggish transfer periods permit the base metal to lose its preheat. Consequently, the deposit is partly oxidized, the fusion is poor, and the shape of the deposit is a high-crowned bead. The deposit obtained with 0.14-0.18 per cent carbon is less contaminated, is somewhat dense, and assumes a more favorable contour. However, the deposit is still prone to contain some iron nitrides, the presence of which in small fractional percentages, renders steel brittle. Therefore, bare ferrous electrodes are used only for "tacking."

In order to eliminate the above short-comings of bare wire electrodes, the final improvement in electrode design came with the advent of shielded arc or covered electrodes. There are two types of coatings, *inorganic* and *organic*.

The matrix of the inorganic coating consists usually of oxides of silicon, aluminum, manganese and titanium in various ratios and quantities per unit length. The matrix of the organic type coatings contains 15-20 per cent volatile organic substances such as wood,

paper, or vegetable fibres—even burned sugar—*in addition to the above mentioned oxides.* Both types of coatings serve the same purpose and perform in the manner described below.

With the *organic* type electrode, the refractory substances of the coatings have a higher melting point than the core they surround. Thus during the formation periods, each drop is surrounded by an extension of the refractory sleeve, which holds it by capillary attraction as though it were in a small crucible. During the formation periods the organic substances contained in that portion of the sleeve which forms the crucible, become volatilized and protect the tip of the electrode from contamination by the ambient air, with a gaseous shield of their neutral atmosphere. The drop forms inside the crucible until it develops a definite size and fluidity, whereupon its surface tension becomes insufficient to hold it within the crucible against the expelling force of the gases generated by itself and liberated from the coating. The drop is then hurled across the arc to the base metal.

The advantages of the coated electrode are as follows:

(*a*) Prolonged formation periods—hence long preheating time of the base metal.

(*b*) Shielding simultaneously the nascent weld metal during its formation period and the preheated base metal.

(*c*) Relatively short transfer periods.

Advantage (*a*) combined with (*c*) results in good fusion and fairly flat and smooth bead formation. Advantage (*b*) results in dense, non-contaminated weld metal of desirable physical characteristics. The slag which forms, as the inorganic portion of the coating melts away, is transferred through the arc also. It floats on the weld metal and, acting as a heat insulator, prolongs its period of solidification, thereby enabling it to vent its occluded gases and thus further insure the density of the weld. The slag coating over the deposit further aids the gas shield to prevent atmospheric contamination prior to its solidification.

The *inorganic* type electrode performs in exactly the same manner as the organic type. The difference between the two types consists of the greater volume of covering matrix per unit length in the case of the inorganic type electrode. This greater volume enables the further prolonging of the preheating period.

The metal transfer is more rapid than in the case of the organic electrodes, as the large volume of gases liberated from the covering develops greater pressure within the crucible. The greater volume of slag transferred helps to take full advantage of the long preheat periods so that the weld metal flattens out, permitting the effortless deposition of successive layers.

The disadvantage of the *inorganic* electrodes is that they are generally suitable with work in the horizontal plane or at very moderate inclinations only.

The *organic* type electrodes are known as universal electrodes (in the sizes of 1/8-inch and 5/32-inch diameters) because, due to the lesser volume of slag deposited, they are most suitable for welding at any angle of elevation or position.

SELECTION OF WELDING ELECTRODES.

The following factors must be considered in selecting welding electrodes:

(*a*) Composition of the base metal.
(*b*) Physical characteristics of the weld metal.
(*c*) Surface contour of the joints to be welded.
(*d*) Weight of the members or wall thickness at the joint.

There are two important reasons why the weld metal should be of approximately the same chemical composition as that of the base metal. The first one is the prevention of corrosion by electrolysis in the presence of an electrolyte. The second is the avoidance of the development of thermal stresses which may assume dangerously high values at elevated temperatures due to different coefficients of expansion of the base and weld metals. Both of these considerations are of prime importance in the Naval Service.

The physical characteristics of the weld metal obviously must be equal to or, whenever possible, superior to those of the base metal. When this exists, increasing the cross-section through the joint is not warranted. When the weld metal is physically inferior to the base metal, the design of the joint must compensate for its weakness. Increased strength is obtained by increasing the cross-sectional area through the throat of the weld *and* overlapping the seal beads to such an extent that they provide sufficient areas in shear to supplement the original cross-section in tension.

When the welding may be performed in the flat position the best workmanship may be expected, as in this position the largest size electrodes, which are in proportion to the wall thickness at the joint, may be used. The best thermal conditions may also be developed, and consequently the best microstructure may be obtained in the resulting weld metal. When the joint surfaces are in the vertical plane or are overhead, then the electrode size is limited by the mechanics of position welding only, regardless of the dimensions of the wall thickness at the joint. Overhead welding can not be successfully performed with electrodes larger than 5/32-inch in diameter.

Incidentally, position work, such as welding in the vertical plane or overhead, due to its inherent imperfections, is seldom permissible in the construction of power plant equipment. It is used only when unavoidable, such as in making emergency repairs.

ARC WELDING POWER SOURCES.

Arc welding may be performed with either the D.C. or A.C. arc. The source of the current may therefore be a generator set or a welding transformer. The use of the former is at the present time more general than of the latter. Generators are built along three specific lines of performance characteristics; viz., constant potential, constant energy, and constant current generators. The three types, in the order given, represent the chronology of their development.

Constant potential type generators, as the name implies, are designed to operate maintaining a constant terminal potential. Consequently, the current passing through the welding arc is nearly a linear function of the arc gap, the major resistance in the welding circuit. As the actual length of the arc gap is usually about ⅛ inch, it is evident that a 1/32-inch variation of the arc gap causes a corresponding 25 per cent variation of the current rate. It will be remembered that the melting rate of the electrode is a function of the current rate. The momentary shortening of the arc gap causes the deposit to pile up before the welder realizes the necessity for changing the rate of progression. The weld metal deposited during the surge of the shortened arc period is not bonded sufficiently due to lack of the time element to preheat the base metal for its recep-

tion. When the arc gap is increased, the current decreases and the melting rate also decreases. In this case the preheating period is unduly long and the volume of the deposit is insufficient to cover the remelted base metal. In consequence, the kerfs become undercut, preventing the maintenance of a steady arc stream during the deposition of the superimposed layer.

The generator performance described above is undesirable for the production of high grade welds; therefore, constant potential generators should be used only for tacking and for such work where such performance may be tolerated.

Constant energy generators are designed to maintain a constant energy output regardless of resistance variations of the welding circuit. In the following it is assumed that the value of the resistance fluctuations is restricted to such unavoidable minimum changes in the length of the arc gap as are incidental to manual welding. The following numerical values are given to illustrate the behavior of constant energy machines:—Given a set adjusted to deliver 100 amperes against a potential drop of 20 volts across a ⅛-inch arc gap. Shortening the arc to 18 volts (corresponds to reducing the length of the arc gap by about 1/32 inch) causes the current to increase to

$$\frac{20 \times 100}{18} = 110 \text{ amps., or a 10 per cent increase.}$$

Similarly, lengthening the arc by 1/32 inch, which increases the potential drop to about 22 volts, changes the current rate to

$$\frac{20 \times 100}{22} = 90 \text{ amps., or a 10 per cent decrease.}$$

The melting rate of the electrode changes according to the ratios

$$\frac{110^2}{100^2} \text{ and } \frac{90^2}{100^2} \text{ or about 20 per cent.}$$

Constant current type generators as a source of welding power are the latest development. They are so designed that the current delivery changes less than 10 per cent following such small potential variations as mentioned above. Accordingly, the melting rate of the electrodes also remains fairly uniform. The consequent reduction of current surges helps the deposition of well bonded

layers of smooth surfaced weld metal, and the major deficiencies of the constant potential and constant energy types are avoided. The diagrams and the tabulation on Figure 1 illustrate the above given characteristics of the three types of welding generators.

Practically all generators are equipped with either separate or built-in reactors. These serve to smooth out the major current surges which occur every time the arc gap is varied. The performance of welding machines is greatly influenced by the constancy of the potential of the primary or motor circuit. If the latter varies more than 2 or 3 per cent of the normal line voltage, the speed of the driving motor varies also and changes the power output of the generator. Under such conditions good welding can not be performed regardless of the type of welding set used. The size, condition and length of the welding cables as well as the type of cable splices used are of major importance also, as these factors may influence the drop of potential at the arc and so change the current rate.

The heavy current of the welding arc under certain circumstances sets up a strong magnetic field around the arc, which prevents the smooth continuity of the arc stream. The arc is wild and to all appearances behaves as though affected by a strong current of air. This phenomenon occurs generally at the end of a plate assembly or in corners. By placing the ground clamp close to that portion of the weld where the disturbing blow exists, and by positioning it so that the path of the current may be diverted from the plate end or from the junction, the effect of the magnetic blow may be eliminated or reduced. The ground connection must be properly secured at all times; it should be of sufficient cross-sectional area to transmit the current without becoming heated.

Fusion welding is also performed with the use of A.C. drawn from a transformer. It is used particularly for heavy work such as fabricating pressure vessels. The marked advantage of A.C. welding is the freedom from the effects of magnetic blow. The transformer is a single phase unit so designed that the current characteristic approaches that of the constant current D.C. generator. The A.C. output is regulated by tap changing devices connected to the primary and by movable core pieces, and by changing the resistance by means of altering the air gap in the

Arc Gap	Constant Potential		Constant Energy		Constant Current	
	Amperes	Melting Rate	Amperes	Melting Rate	Amperes	Melting Rate
3/32	180	1.44	170	1.25	155	1.07
1/8	150	1	150	1	150	1
5/32	120	0.64	138	0.85	140	0.87

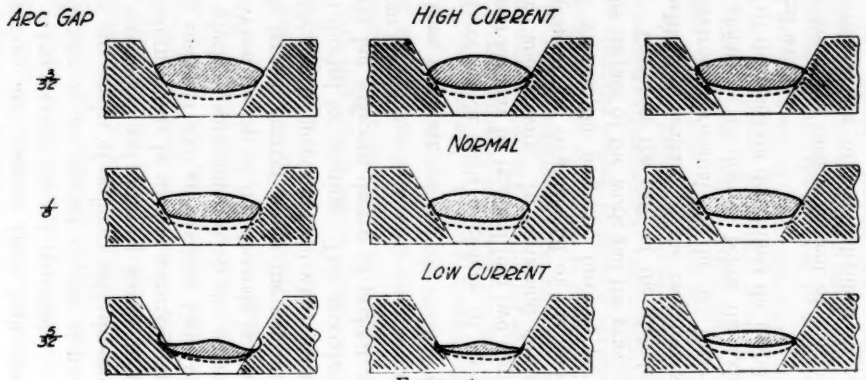


FIGURE 1.

reactor. The latter methods provide an infinite number of steps for the regulation of the current rate. Arc welding transformers are bound to remain strictly shop equipment for some time due to certain inherent characteristics of A.C.,; *i. e.,* self-induction in the lead wires, direct induction, and dangers from high open circuit voltage (80-100) if safety devices are not provided.

There is an A.C. transformer on the market of 120 ampere rating which may be used by any welder of ordinary skill, depositing metal from 1/16-inch electrodes, and drawing hardly more than 20 amperes. This transformer may be used at a current rate as low as 10 amperes. It is equipped with an auxiliary high frequency coil the output of which is superimposed on the output of the main transformer. When the tip of the electrode is held close to the work, the high tension current jumps the gap and creates an ionized path for the low frequency current which starts flowing without having been shorted for starting. This procedure permits starting with a slight but sufficient degree of preheat so that the deposit is fused from the start.

POSITION WELDING.

Vertical Welding—The force which hurls a globule of weld metal from the tip of an electrode may be resolved into two components; *i. e.,* magnetic force and gravity. In horizontal downhand welding the two components are co-axial and of the same algebraic sign. In vertical welding the magnetic force is perpendicular to the plane of the surface of the work and the gravity component is parallel to it. Therefore the path of the globules through the arc coincides with the resultant of the two forces. Example:—work vertical; electrode horizontal—If the two forces are equal, the path of the globule is 45 degrees below the axis of the electrode. The angle of the resultant determines the usability of an electrode for vertical welding.

As tests have shown, the lower the carbon content of a mild steel electrode, the greater the weight of the individual drop. Conversely, the higher the carbon content, the smaller the drop. This being the case, the lower the carbon content the greater the danger of the weld metal drooping or bunching on the already deposited weld metal, and the deeper the crater directly opposite the electrode.

When the carbon content is high, the deposit is hurled almost directly opposite the electrode. The last deposit remains the target of the arc and becomes superheated, though the base metal beneath it is not sufficiently preheated.

Thus it is seen the most suitable electrode for vertical welding is one of such carbon content which permits the development of medium weight globules, the formation periods of which are sufficiently long to permit good preheating of the base metal without undercutting. The carbon range suitable for position work has been found to be quite narrow, 0.08 to 0.14 per cent with electrodes designed for use with reversed polarity, and 0.14 to 0.18 per cent with those suitable for straight polarity or A.C. deposition.

Vertical welding must be performed from the lowest point upward. When the weld is built up in the proper manner, the top of the column is the hottest part and is in the most fluid state. Therefore, the impurities are permitted to float off and the entrained gases allowed to escape. The target of the arc is the base metal above the hot deposit, hence good penetration of the weld is automatically assured. Vertical welding downward traps the impurities and gases and prevents a good weld. Therefore it should never be permitted. The above comments concerning vertical welding are illustrated diagrammatically on Figure 2.

Overhead Welding—In overhead welding the two forces acting upon the globule of melted electrode are co-axial but of opposite algebraic signs. Consequently, when the values of the two forces are equal, overhead welding can not be accomplished. This again reduces the usefulness of the low carbon content electrode and favors the higher carbon content types.

The long preheating periods of the *low carbon* (0.06-0.08 per cent) electrodes cause the base metal to liquefy in the crater. This condition of low viscosity of the remelted base metal prevents the globules from spreading out. The consequence is that the deposit assumes a high crowned contour. This condition makes the deposition of the subsequent bead or layer difficult and the formation of slag pockets almost inevitable.

The preheating periods of the *medium carbon* (0.12-0.15 per cent) electrodes is shorter, and consequently the base metal in the

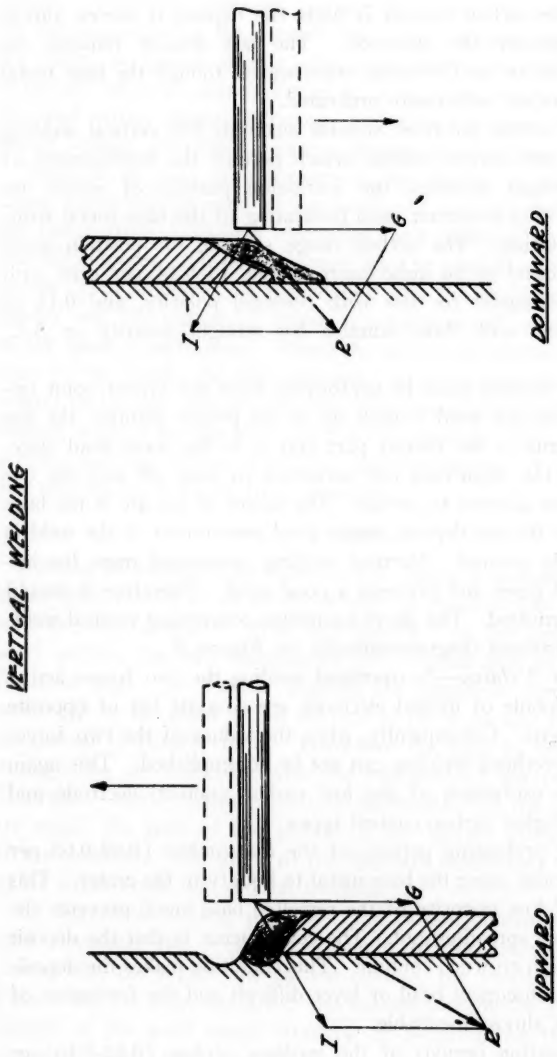

VERTICAL WELDING
DOWNWARD
UPWARD
I
G
2
I-MAGNETO-MOTOR FORCE
G-GRAVITY.
2-RESULTANT.

FIGURE 2.

crater is not liquefied to the extent as under the arc of the 0.06-0.08 per cent electrodes. The viscosity of the pasty base metal in the crater is higher and the shape of the deposit more satisfactory to receive subsequent layers.

The preheating period of the *high carbon* (0.25-0.28 per cent) electrodes is in proportion to the volume of the individual globule of weld metal. It is sufficient to preheat the base metal to a pasty condition, but the viscosity of the lower melting point weld metal is somewhat low. In consequence, the deposit does not cover the entire preheated area of the crater and tends to form a high crowned bead.

POSITION WELDING WITH NON-FERROUS ELECTRODES.

Most non-ferrous electrodes develop large individual globules when used in arc welding. Therefore in vertical welding the gravity force acting on the globule is much greater than the magnetic force and the globule is dropped below the crater in the base metal upon the already chilled deposit. Thus a vertical weld made with a non-ferrous electrode is unreliable, containing unexpelled impurities and blow holes.

Overhead welding with non-ferrous electrodes in most cases can not be performed because the gravity factor often exceeds the magnetic factor. When conditions do permit the transfer of the electrode through the arc, the viscosity of the deposit is often too low to permit it to spread. Then the deposit tends to form a tear drop and break away from the base metal.

PREPARATION OF BASE METAL FOR ELECTRIC ARC WELDING.

The condition of the surface of the base metal prior to arc welding is an important factor in the final quality of the weld itself. Smoothness of the surface on which weld metal is to be deposited is essential for producing dense, well-bonded welds. It is likewise important that such surfaces be free from oxides, paint or oil films, or any other substances which will contaminate the freshly deposited metal.

The volume and contour of the scarf (the space between the members to be joined) is another important factor. The width of the scarf generally does not need to be greater than that minimum which permits the unobstructed manipulation of the elec-

trodes. The governing factor of the width of the root spacing of the scarf is therefore the electrode diameter, which is chosen to be proportional to the wall thickness of the joint. In well designed structures the width of the root spacing is usually given as 1.5 to 2 times the overall diameter of the smallest electrode used in the root of the weld.

As the arc naturally seeks the path of least resistance, it is evident that sharp corners; *i. e.,* junction of members at acute angles, must be avoided.

The included angle of the scarf does not need to exceed 60 degrees. Whenever possible this angle should be kept smaller to reduce the volume of weld metal used to a minimum. Experienced welders are capable of producing sound and well-bonded deposits in scarfs having an included angle of not over 14 degrees. When the wall thickness is considerable; 1 inch or over; then for economical reasons alone, it is advisable to keep the included angle of the scarf to a minimum, seldom above 10 or 12 degrees.

The method of forming the kerfs for welding varies according to the composition. Mild steel may be torch cut to the approximate shapes desired. However, the torch-cut edges must be machined off to a depth which is beyond the limit of the fine thermal cracks which are certain to appear in torch-cut surfaces of steel. Alloy steels and cast iron should not be torch-cut under any circumstances. The machining of cast iron in preparation for welding is not desirable but when it can not be avoided, cutting oil must not be used. Non-ferrous metals may be machined prior to welding but the use of cutting oils must be avoided. When the material to be welded is covered with paint, oily grime, grease, or deposit not readily removable by mechanical means, sand-blasting is recommended.

Before passing on to oxy-acetylene welding, let us consider some of the welding errors and their resulting defects found in arc welds. Some defects may be detected during the actual operation of welding, some by visual examination of the finished weld, and others by machining the weld and testing. The most common welding errors, with their resultant defects, are tabulated below. An intimate knowledge of the table will contribute a great deal to the understanding of successful arc welding.

A. *Too Low Current.*
1. Lack of fusion.
2. Slag inclusions ("chill effect").
3. Porosity ("chill effect").
4. Undesirable contour.

B. *Too High Current.*
1. Undercutting.
2. Porosity (due to excessive gassing).
3. Low deposition efficiency (due to spatter loss).

C. *Too Short An Arc.*
1. Danger of frequent sticking of electrode to work. (Each sticking means unfused metal).
2. Too high melting rate of electrode and uneven fusion.

D. *Too Long An Arc.*
1. Undercutting.
2. Porosity.

OXY-ACETYLENE WELDING.

Welding with the oxy-acetylene torch is a procedure basicly analogous with the shielded arc method. The source of heat is independent of the welding rod and the sequence of events are not automatic but are controlled by the welder. The deposition of weld metal resolves itself on repeating the cycle of preheating the base metal to a semi-plastic condition—and simultaneously preheating the welding rod to a temperature of not more than 1500-1800 degrees F. When the base metal reaches the desired temperature, the welding rod is advanced into the heat zone and a small volume is melted off and deposited upon the plastic base metal.

The drops melted off the tip of the welding rod are transferred onto the work partly by gravity, but mostly by capillary attraction, as the welding rod is in direct contact with the deposited metal at the instant it is advanced under the inner cone of the oxy-acetylene flame. The outer envelope of the flame provides a neutral atmosphere which protects from atmospheric contamination, the molten puddle of freshly deposited metal, the preheated end of the electrode, and the weld metal, during the period it is melted off the rod and is transferred to the work.

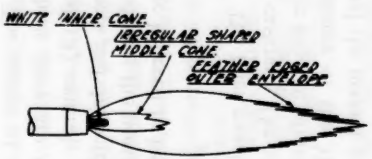
The fact that the weld metal is deposited mostly by capillary attraction enables the use of gas welding in any position.

The practical consideration of this method of welding does not permit the use of welding rods of such widely varying composition as given for electric arc welding. Steels containing carbon over .06-.08 per cent and over .35 per cent Mn develop an undue amount of gassing so that the weld metal deposited from such rods is very porous and therefore useless for construction purposes. The commonly used welding rods are of low carbon content and copper-coated. The copper coating serves to lower the melting point of the rod and thus aids in reducing gassing. During the transfer of the weld metal a slight amount of the carbon content of the core is reduced. The deposit is therefore a carbon-poor steel which has all the characteristics of such as far as tensile strength and ductility are concerned. If higher tensile strength is required of the oxy-acetylene deposit special welding rods are used. These usually contain a small percentage of nickel—up to about 1.5 per cent—and/or a small percentage of vanadium, or some other efficient scavenger. These rods are of somewhat higher carbon content, and therefore the copper coating is not used.

The inspection of a finished assembly by visual means only is just as deceptive as in arc welding. While it is generally true that the neatness of the work denotes good workmanship, it does not necessarily mean that the neat work is always an efficient welding job.

Visual inspection of the welding while in progress permits the observation of important factors which influence the quality of the weld. These factors are: (1) method of welding used (back hand or fore hand), (2) degree of preheat, (3) adjustment of flame.

The term "back hand" refers to the relative position of the welding rod and flame in regard to the progression of the welding. When the torch leads the direction of progression—(when it is held pointing *back* to the crater)—the "back hand method" is used. This is correct for welding ferrous metals. The reverse of this, the "fore hand" method, is used often in welding or brazing non-ferrous metals.



NOTE THE PRESENCE OF THE SHORT INNER CONE, THE ABSENCE OF THE MIDDLE CONE AND THE SHORT SHARPLY OUTLINED FLAME ENVELOPE. THIS FLAME IS CHARACTERISED BY A HISSING SOUND.

PRACTICALLY SOUNDLESS.

CARBONISING OR REDUCING FLAME IS PRODUCED BY BURNING AN EXCESS OF ACETYLENE.

IT HAS A TENDENCY TO INCREASE THE CARBON CONTENT OF THE SURFACE OF THE BASE METAL AND THEREFORE LOWER THE MELTING POINT. THUS THE SPEED OF WELDING IS INCREASED.

RESULT: A FILM OF BRITTLE HIGH CARBON CONTENT METAL AT THE FUSION ZONE WHICH REDUCES THE DUCTILITY AND SHOCK RESISTANCE OF THE JOINT. (IN CASE THE BASE METAL IS STEEL.)

OXIDISING FLAME IS PRODUCED BY BURNING AN EXCESS OF OXYGEN.

IT SPEEDS UP THE RATE OF WELDING BUT OXIDISES BOTH THE BASE METAL AND THE WELD METAL.

RESULT: POROUS DEPOSIT OF LOW TENSILE STRENGTH AND DUCTILITY.

(ABOVE CONDITION REFERS TO ANY TYPE OF BASE METAL.)

NEUTRAL FLAME IS PRODUCED WHEN THE GAS MIXTURES ARE CORRECTLY PROPORTIONED. THE INNER CONE IS LARGER THAN THAT OF THE OXIDISING FLAME BUT SHORTER THAN THAT OF THE REDUCING FLAME. THERE IS NO MIDDLE CONE. THE OUTER ENVELOPE IS ALMOST AS LARGE AS THAT OF THE REDUCING FLAME BUT IT HAS NO FEATHER EDGE.

USES OF THE VARIOUS FLAME ADJUSTMENTS.

MATERIAL.	TYPE OF FLAME.
STEEL AND FERROUS METALS.	NEUTRAL
COPPER BASE ALLOYS.	NEUTRAL BUT SLIGHTLY REDUCING. *
STELLITE.	REDUCING
ALUMINUM ALLOYS.	REDUCING
MAGNESIUM ALLOYS.	REDUCING
SILVER SOLDERING.	SLIGHTLY REDUCING.

* A SLIGHTLY REDUCING ADJUSTMENT IS OBTAINED WHEN THE OUTER ENVELOPE IS RAGGED EDGED, BUT WITHOUT MAINTAINING A MIDDLE CONE. IT IS OBTAINED BY FIRST ADJUSTING FOR A REDUCING FLAME AND THEN CUTTING DOWN ON THE ACETYLENE SUPPLY UNTILL THE MIDDLE CONE DISAPPEARS ALMOST ENTIRELY.

FIGURE 3.

The source of heat is the flame of an oxy-acetylene torch, of which there are three types; viz., (1) reducing, (2) oxidizing, and (3) neutral. The sketches on Figure 3 explain the appearances and characteristics of each type flame and the tabulated legend indicates the uses of the various flame adjustments. The sketches are believed to be self-explanatory.

METALLURGY OF FUSION WELDING.

The filler metal deposited by either method of fusion welding is a casting. The purity of the electrodes or rods, the shielding of the arc, the proper method of deposition, the delicately controlled balance of the Mn-C content of the electrodes or welding rods, and the neutral gas flame—all make possible the transfer of weld metal without contamination. Consequently the weld metal may be expected to be purer than the base metal members which it unites. The deposited weld metal therefore has a higher tensile strength than is usually specified for cast steel of similar composition. Why?

(1) The high quality of the weld metal.

(2) The difference between the microstructures of commercial steel castings and weld metal in general, and the arc deposited weld metal in particular.

The above remarks concerning the purity of the weld metal need no further discussion. The microstructure of commercial cast steel, in the "as cast" condition, is coarse. To render castings useful, it is necessary to heat-treat them to develop the desired grain structure and to relieve the residual shrinkage stresses.

The usual heat-treatment given castings is known as "annealing," consisting of heating slowly beyond the critical, and maintaining for a sufficient time to cause recrystallization throughout the mass. Then the temperature is lowered slowly to 1150-1200 degrees F. and held for a sufficient time to permit the adjustment of the residual stresses. Finally the casting is permitted to cool in the furnace slowly to room temperature.

The grain size developed in annealing is large and fairly equiaxed. Mild steel treated to develop such grain structure possesses high ductility but the tensile strength is much lower than it was in the "as cast" condition.

Examining the microstructure of a single bead of weld metal deposited by arc welding, the microstructure reveals the typical ingot structure of raw cast steel. Re-examining the microstructure of the same bead after another bead is deposited upon it, it is found that the first layer underwent a complete structural change. It consists of equiaxed fine grains throughout. However, the structure of the second bead is the same coarse ingot structure as that of the first bead prior to the deposition of the second.

Normalizing of mild steel is a heat-treatment which consists of heating to above the critical, holding above the critical until recrystallization takes place throughout, removing the steel from the furnace, and allowing it to be quenched in air.

The coarse grained metal deposited by arc welding becomes normalized from the heat effect of the superimposed layer. The conditions peculiar to arc welding are such that the temperature developed in the weld metal *under* the arc is above the critical but seldom exceeds 1750 degrees F. The volume of the weld metal affected by the heat input of the superimposed layer depends on two factors; first, there is the volume or, correspondingly, the heat input from the superimposed metal; second, there is the residual temperature of the lower layer.

The quenching effect, which completes the process of normalizing each layer of weld metal, is due to the rapid loss of temperature from the weld zone into the mass of the base metal. It is a peculiar characteristic of arc welding that the heat input of each succeeding layer is sufficient to cause the complete recrystallization of the previous layer providing the temperature of the previous layer is not less than 200-250 degrees F.

The microstructure of the filler metal deposited by means of the gas welding process is dependent upon the heat conditions which obtain during the period the temperature of the nascent metal of the deposit is above the critical, and the maximum degree of temperature maintained during that period.

Gas welding practice calls for filling in the scarf by depositing as few layers as possible. Each layer of metal deposited is covered by a thin film of oxide, which must be thoroughly dissolved and slagged off during the deposition of each superimposed layer of weld metal. To avoid this complication the scarf is filled in with

as few layers as conditions permit. The consequent slow rate of progression permits the conduction of part of the heat input into the base metal.

The elevated temperature of the base metal surrounding the weld zone does not quench the weld metal as in arc welding. The above thermal conditions are analogous to those which obtain in annealing. The grain structure of mild steel deposited by gas welding is typical of low carbon steel annealed at or near the maximum temperature for the development of equiaxed grains.

NAVAL WELDING PROCESS APPROVAL TESTS.

By William C. Stewart.*

In this article, Mr. Stewart has assembled for the first time the scattered information and instructions which the Bureau of Engineering and the Experiment Station have issued from time to time, to manufacturers interested in naval machinery on which welding is permissible. Until further advances are made in the art, this discussion of naval proving methods should be of the greatest value to manufacturers of naval and marine machinery interested in keeping up with the Navy's inspection requirements.

Welding process approval tests in connection with fusion arc welded construction for boiler drums used in the scout cruisers, *Minneapolis, New Orleans* and *Astoria,* began at the U. S. Naval Engineering Experiment Station in 1930. Since that time, welding process approval tests have been extended to cover welding of steels for high temperature service; such as, carbon-molybdenum, manganese-molybdenum, chromium-molybdenum and 4 per cent to 6 per cent chromium .5 per cent molybdenum steels. More recently, these tests have been required for the welding of a number of alloys; namely, copper-nickel alloy, bronzes, scale-resisting alloy and corrosion-resisting steel.

The acceptance by the Navy of a welding procedure is based on a number of requirements depending upon the purpose and importance of the structure to be welded.

The plant of a fabricator proposing to weld important structures such as boiler drums is inspected by Navy representatives in order to determine whether suitable equipment is available for this type of work.

At the present time, it is required that all circumferential and longitudinal seams in boiler drums be welded by an automatic

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welding process. Consequently, equipment for this purpose must be available before the initial requirements of the approval process can be met. The soundness of weld seams in boiler drums is of such great importance that the Navy requires that the circumferential and longitudinal weld seams be radiographed before acceptance. This requires either the installation of X-ray equipment adaptable for the metal thicknesses involved or the application of Gamma-ray radiography, involving the use of radium. Finally, the structure must be stress relieved as a unit at approximately 1200 degrees F. temperature. This requires a furnace of large size with reasonably good temperature control.

From the above brief description it will be noted that for important welded structures, considerable welding equipment and inspection apparatus are necessary before the manufacturer can comply with the initial requirements of process approval for welding of boiler drums.

The necessary welding equipment, accessory equipment and inspection apparatus being available, it is necessary that suitable welding electrodes be available for the purpose at hand.

Information and requirements for process approval tests are set forth in printed forms entitled, "Instructions for Approval of Welding Process." A separate set of instructions has been prepared by the Bureau for different materials involving welding.

Process approval tests for the welding of boiler drums are covered in General Specifications for Machinery. Leaflet instructions for process approval of the following are available:

Copper nickel alloy (60 per cent nickel minimum)
18 per cent Chromium—8 per cent Nickel steel (CRS Grade 1)
Scale Resisting Alloy (25 per cent Cr.—20 per cent Ni.)
4—6 Chromium—.5 per cent Molybdenum steel
Carbon-Molybdenum steel.

Since much of the matter contained in the above-mentioned "Instructions for Approval of Welding Process" is of a general nature, these instructions can be made the basis of procedure for the welding of materials other than those specified. For example, the instructions for welding carbon-molybdenum steel are applicable to the welding of manganese-molybdenum and chromium-molybde-

num steels, providing supplementary information concerning the required physical and chemical properties, electrodes, conditions of preheat and other information is given.

Process approval tests are authorized by the Bureau of Engineering only after a written request has been received from the contractor giving the chemical and physical properties of the material it is proposed to weld and information regarding the application of the welding and the use of the welded product. When authorized, these tests are conducted in two phases. The first phase involves the preparation of a test plate in the presence of the Inspector and the compiling of data by the Inspector in the manufacturer's plant. The second phase involves the testing of the finished product at a Government laboratory.

A test plate of a definite type, depending on the material and the purpose for which the welding practice is to be used, is prepared by one of the contractor's welders for approval of the welding process. Welding of this test plate is witnessed by the Naval Inspector, and the data required by test data sheet is recorded in duplicate. The test plate is forwarded to the Naval Engineering Experiment Station, Annapolis, Maryland, for test. One copy of the test data sheet is also forwarded to the Engineering Experiment Station.

The chemical and physical properties of the base material of the test plate are given in "Instructions for Approval of Welding Process." For some materials, these requirements are also covered by Navy Department Leaflet Specifications; for example, copper-nickel alloy (60 per cent Ni. minimum) is covered by Specification 46M7e and corrosion-resisting steel by Specification 46S18. The above-mentioned instructions also set forth the physical and chemical requirements for the weld and weld metal. Likewise, special information as regards preheating, approved type of electrodes, position of welding and heat treatment after welding is given in these Instruction Sheets.

After approval of the welding process by the Bureau of Engineering, the welder who prepared the test plate for approval of the welding process is considered automatically qualified to weld material of the type tested under certain restrictions as regards position of welding and plate thickness. As would be expected, these re-

strictions differ for different materials. Moreover, after the process of welding has been approved by the Bureau, qualification tests of welders may be conducted by the Naval Inspector.

PROCESS APPROVAL FOR WELDING OF CLASS A-1 PRESSURE VESSELS.

As previously indicated, welding of the pressure parts of boilers will not be approved by the Bureau of Engineering unless the manufacturer has fully demonstrated to the satisfaction of the Bureau his ability to perform such welding in full accordance with the requirements of Class A-1 pressure vessels specified in Subsection S1-2, General Specifications for Machinery, and has the necessary equipment for proper inspection. Departure in any detail from the above specifications, including the type and characteristics of electrodes used, will require special investigation by the Bureau prior to approval. Moreover, the detailed design of all welded joints used for pressure parts of boilers shall be satisfactory to the Bureau in every particular.

When these requirements have been complied with by the manufacturer, a test plate for process approval is prepared. Ordinarily representative welded sample plates may be obtained by tack welding plates to the ends of a longitudinal joint in a drum shell, the plates being located so that the welding is performed at the same time and under the same conditions as the corresponding longitudinal seam of the drum shell. This procedure is particularly applicable for welds made by an automatic welding process. However, since process approval is required before drums are fabricated, it is necessary that the test plate be prepared independently of the drum. Figure 1 presents a sketch showing the location of various test specimens in a test plate used for process approval for welding of boiler drums. This test plate is provided with two parallel weld seams, as will be noted from the figure. The two weld seams make it possible to obtain tension specimens provided with holes simulating boiler tube holes. One hole is located tangent to the weld, another through the weld and the third through the base metal. On pulling the section, the comparative strength of the base and weld metal is obtained directly. Moreover, information is obtained as to the relative distortion of the three tube holes as the

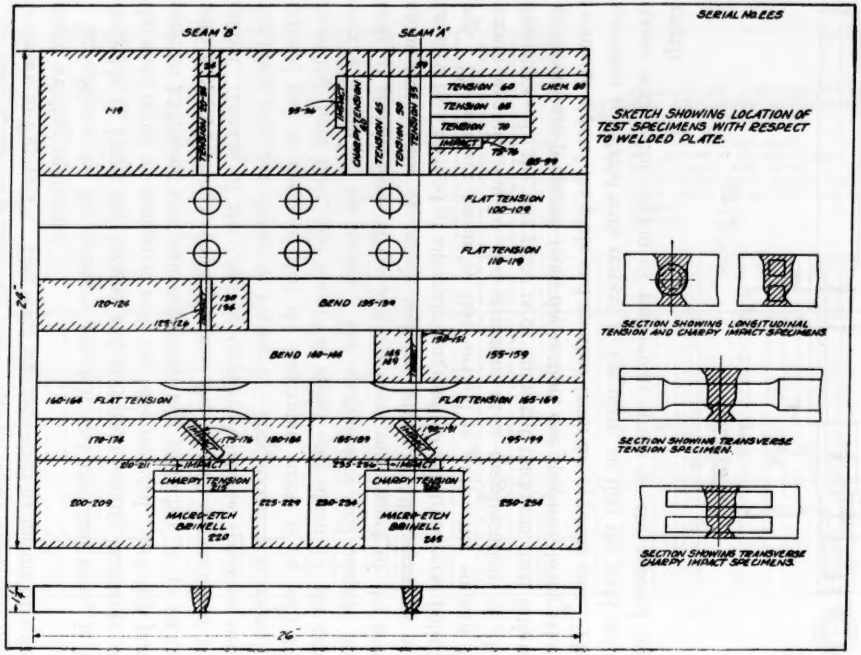

SERIAL Nos. 665
SEAM "B"
SEAM "A"
1-19
TENSION 60
CHEM. 60
TENSION 65
TENSION 70
IMPACT
70-76
65-69
CHARPY TENSION
TENSION 45
TENSION 50
TENSION 55
FLAT TENSION 100-109
FLAT TENSION 110-119
120-126
BEND 125-134
BEND 150-156
155-159
160-166 FLAT TENSION
FLAT TENSION 165-169
170-174
175-176
180-184
185-189
195-199
IMPACT
CHARPY TENSION
200-209
MACRO-ETCH BRINELL 220
225-229
230-234
MACRO-ETCH BRINELL 249
250-254
24"
1-1/4"
26"
SKETCH SHOWING LOCATION OF TEST SPECIMENS WITH RESPECT TO WELDED PLATE.
SECTION SHOWING LONGITUDINAL TENSION AND CHARPY IMPACT SPECIMENS.
SECTION SHOWING TRANSVERSE TENSION SPECIMEN.
SECTION SHOWING TRANSVERSE CHARPY IMPACT SPECIMENS.

FIG. 1

result of a tensile pull. Specimens for tension, impact, bend test and for macro and micro-examination and millings for chemical analysis are also obtained from the test plate.

A macrograph of a relatively heavy section boiler drum test weld is shown in Figure 11. This weld was deposited by means of automatic welding equipment.

In addition to the ordinary physical and chemical tests, it is desirable to know the fatigue and corrosion-fatigue resistance of the weld metal as compared with the base material. For this purpose an additional test plate approximately 16 inches $\times$ 12 inches with the weld seam extending across the 16-inch dimension is required. Details of the rotating cantilever fatigue specimen used for these tests are shown in Figure 2. This specimen is conically tapered and so designed that the maximum stress is $\frac{3}{4}$ inch out from the inner fillet, and the stress varies only about 1.5 per cent over a length of 1.5 inches. The specimen is well adapted for tests of simultaneous stress and corrosion on account of the generous test length of nearly uniform stress. All specimens are finished by a method of alternate longitudinal and transverse polishing. The surface finish by this method is sufficiently smooth to permit examination of the structure at a magnification of 100 diameters. If the test plate is of sufficient thickness, two fatigue specimens are prepared from the section, one specimen being taken from one side of the plate and another from the opposite side. The specimen is located with respect to the plate, so that the weld seam comes within the region of maximum stress of the tapered test length.

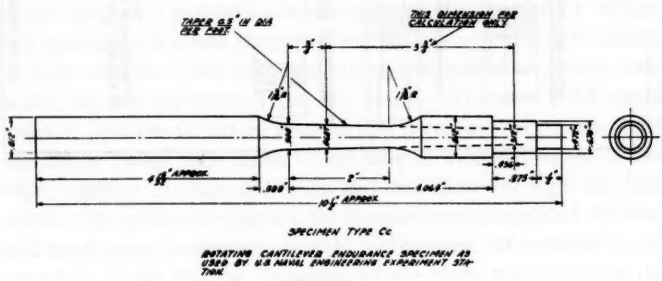


FIGURE 2.

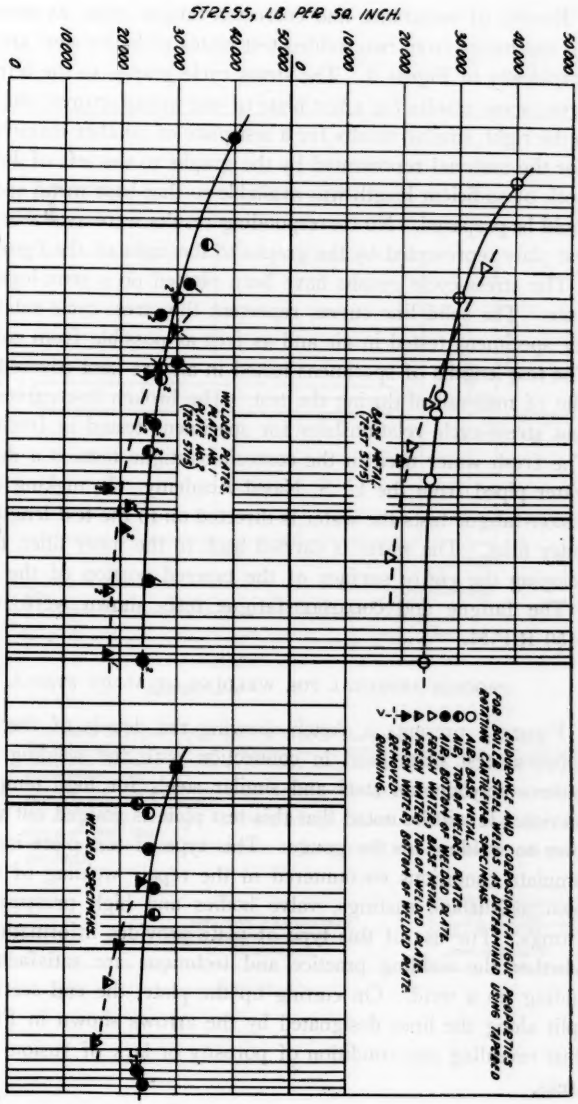

STRESS, LB. PER SQ. INCH.
50 000
40 000
30 000
20 000
10 000
0
10 000
20 000
30 000
40 000
50 000
10⁵
10⁶
10⁷
10⁸
CYCLES
WELDED PLATES. PLATE No.1 PLATE No.2 (TEST STRS)
BASE METAL (TEST STRS)
WELDED SPECIMENS
FATIGUE AND CORROSION-FATIGUE PROPERTIES FOR BOILER CARBON STEEL AS DETERMINED USING TAPERED ROTATING CANTILEVER SPECIMENS.
AIR, BASE METAL.
AIR, TOP OF WELDED PLATE.
AIR, BOTTOM OF WELDED PLATE.
TAP WATER, BASE METAL.
TAP WATER, TOP OF WELDED PLATE.
TAP WATER, BOTTOM OF WELDED PLATE.
SPECIMEN REMOVED.
SPECIMEN RUNNING.

FIGURE 3.

Results of endurance and corrosion-fatigue tests, as determined for specimens from two welded test plates of boiler steel are shown graphically in Figure 3. The stress cycle graphs to the left of the figure show results for a test plate of one manufacturer; the graphs to the right, similar results for a test plate of another manufacturer. For the material represented by the graphs to the left of Figure 3, stock of sufficient length was available so that base metal specimens could be prepared. No corresponding results were available for the test plate represented by the graphs to the right of the figure.

The stress-cycle graphs have been plotted on a semi-logarithmic scale. The solid line curves represent the stress-cycle relationship for specimens tested in air and as free as possible from corrosion. The test lengths of specimens tested in air are kept covered with a film of mineral oil during the test. The broken line curves represent stress-cycle relationships for specimens tested in fresh water. The fresh water used in the corrosion-fatigue tests is a deep well water piped from the U. S. Naval Academy. In making the corrosion-fatigue tests the water is directed on to the test length at the outer fillet. The water is carried back to the inner fillet, thus enveloping the entire surface of the tapered portion of the section.

The fatigue and corrosion-fatigue tests shown were made at 1450 R.P.M.

PROCESS APPROVAL FOR WELDING OF ALLOY STEELS.

Figure 4 presents a sketch showing the details of the process approval test plate used in connection with the welding of cast carbon-molybdenum steel and similar steels for high temperature service. It will be noted that this test plate is gouged out with the view to welding up the gouge. This type of test plate is used to simulate conditions encountered in the repair welding of castings such as turbine castings, valve bodies and high pressure steam fittings. The use of this type of plate provides information as to whether the welding practice and technique are satisfactory for ending up a weld. On cutting up the plate, the end sections are split along the lines designated by the arrows shown in Figure 4, thus revealing any condition of porosity or lack of fusion in these areas.

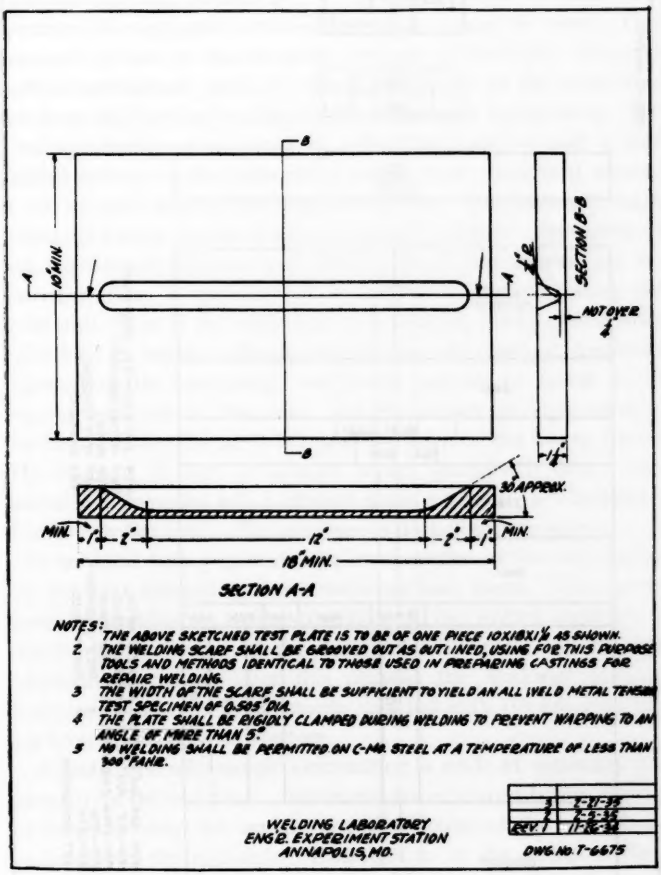

B
10" MIN.
A
A
B
SECTION B-B
NOT OVER 1/4"
1/4"
30° APPROX.
MIN.
1"
2"
12"
2"
1"
MIN.
18" MIN.
SECTION A-A
NOTES:
1. THE ABOVE SKETCHED TEST PLATE IS TO BE OF ONE PIECE 10"X18"X1/4" AS SHOWN.
2. THE WELDING SCARF SHALL BE GROOVED OUT AS OUTLINED, USING FOR THIS PURPOSE TOOLS AND METHODS IDENTICAL TO THOSE USED IN PREPARING CASTINGS FOR REPAIR WELDING.
3. THE WIDTH OF THE SCARF SHALL BE SUFFICIENT TO YIELD AN ALL WELD METAL TENSION TEST SPECIMEN OF 0.505" DIA.
4. THE PLATE SHALL BE RIGIDLY CLAMPED DURING WELDING TO PREVENT WARPING TO AN ANGLE OF MORE THAN 5°.
5. NO WELDING SHALL BE PERMITTED ON C-MN. STEEL AT A TEMPERATURE OF LESS THAN 300° F. MIN.
3 2-21-35
2 2-5-35
REV. 1 11-26-34
WELDING LABORATORY
ENGR. EXPERIMENT STATION
ANNAPOLIS, MD.
DWG. NO. T-6675

FIGURE 4.

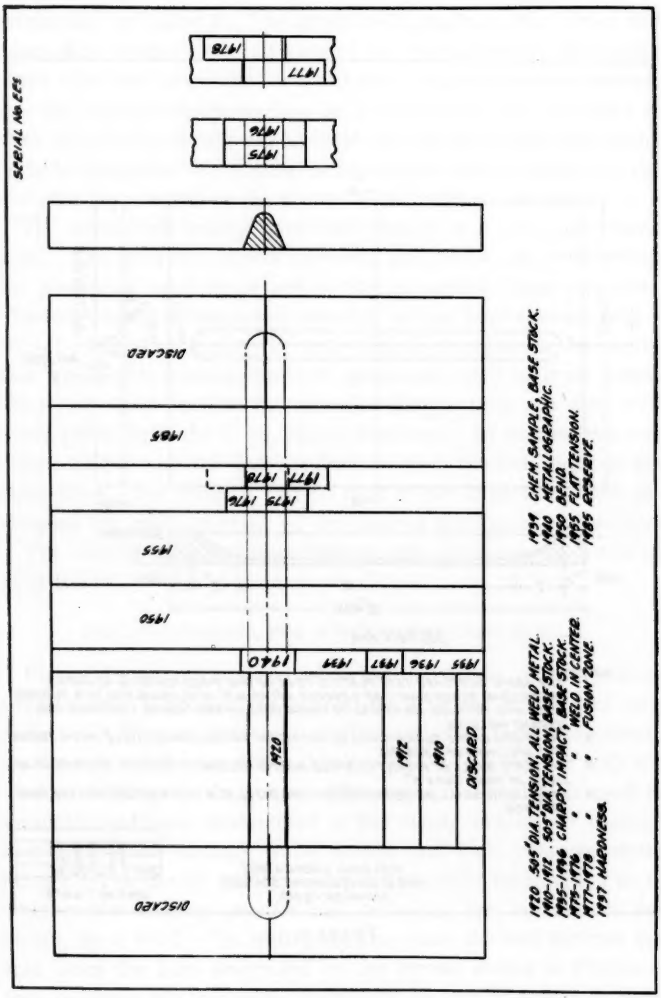

SERIAL NO. EFF
1978
1977
1976
1975
DISCARD
1985
1977
1978
1976
1975
1955
1950
1940
1939
1927
1936
1935
M20
M12
M10
DISCARD
DISCARD
1939 CHEM. SAMPLE, BASE STOCK.
1940 METALLOGRAPHIC.
1950 BEND.
1955 FLAT TENSION.
1985 REVERSE.
1920 .505" DIA. TENSION, ALL WELD METAL.
1910-1912 .505" DIA. TENSION, BASE STOCK.
1935-1936 CHARPY IMPACT, BASE STOCK.
1973-1976 " " WELD IN CENTER.
1977-1978 " " FUSION ZONE.
1937 HARDNESS.

FIGURE 5.

The usual method of locating the various test specimens with respect to the welded test plate is shown in Figure 5. Tension tests of the base metal and all-weld metal are made using standard .505-inch diameter specimens. A tension test is also made of a specimen of rectangular cross-section taken across the weld. This specimen is used to determine the strength of the bond. For cast carbon-molybdenum steel the ultimate strength of the transverse specimen shall not be less than 65,000 pounds per square inch. The bend specimens are mounted on cylindrical supports and a load applied midway of the supports by means of an attachment secured to the movable head of the tension machine. The contact through which the load is applied is also cylindrical in shape. Specimens of cast carbon-molybdenum steel when bent in this manner are required to show a minimum of 30 per cent elongation along the outermost fibers of the weld without developing cracks greater than 1/16 inch in length. Charpy impact tests are made of specimens representing the base metal, weld metal and line of fusion at the top and underside of the weld. For the impact specimen taken at the line of fusion the notch is located so as to test the line of fusion. The A. S. S. T. type of Charpy impact specimen is used. This specimen is provided with a keyhole notch containing a 2-millimeter diameter drilled hole. The specimen is 10 millimeters square.

A hardness survey is made of a cross-section of the weld including the heat affected zone and adjacent base metal. This survey gives information as to the condition of the welded assembly as regards the normality of the deposited weld metal and the heat treatment procedure. For this purpose the Rockwell hardness tester using the 1/16-inch diameter steel ball with 100 kilogram load has been found very satisfactory.

A macro and microscopic examination is made of specimens prepared from the test plate. Specimens are examined before etching, in order to reveal the amount and distribution of the non-metallic inclusions in the materials. Examination of the etched surfaces reveals the structure. A macro-photograph showing the cross-section of the weld is prepared. Likewise, photomicrographs showing the structures for the base metal, weld metal and line of fusion are prepared. A macrograph showing a cross-section of a weld in a cast carbon-molybdenum steel test plate is presented in Figure 12.

On receipt of a test plate, a visual examination is made in order to determine the extent of warpage, workmanship, evidence of undercutting and method of finishing up the weld and depositing the seal beads.

Obviously, if a test plate of cast alloy steel is to be satisfactory as regards the tests enumerated above, it is essential that the cast plate be sound and of good quality. Likewise, it is essential that the base metal be properly heat treated in order to develop the physical properties required by the specifications. After welding, the test plate should be stress-relieved at 1200 degrees F. temperature. Failure to provide a sound test plate or failure to properly heat treat the material will very often result in failure of the process approval test. Under these conditions, the base metal is not sufficiently sound or strong to permit of testing the weld in a satisfactory manner.

Figure 6 presents a welding form supplied to the manufacturer by the Bureau of Engineering for use in connection with the welding of alloy steel process approval test plates. This form containing the information supplied by the manufacturer forms a part of the record of the test.

Since carbon-molybdenum steel and similar alloy steels are used for parts subject to high temperature conditions, it is necessary that information be obtained concerning the creep characteristics of these materials at elevated temperatures. Creep tests require a considerable length of time for completion. Consequently, it is not practicable to make creep tests for each process approval test plate. Accordingly, creep test specimens of base metal and all-weld metal are taken from test plates from time to time. In some cases, test plates have been prepared specifically for use in preparing creep test specimens. In addition to base metal and all-weld metal samples, specimens containing both base and weld materials in the test length are tested. For the most part creep tests of the alloy steels have been confined within the temperature range 650 to 850 degrees F. for the reason that these materials find most application within this temperature range. Creep tests have been made of cast and forged carbon-molybdenum steel including the deposited weld metal, cast manganese-molybdenum steel and the deposited weld

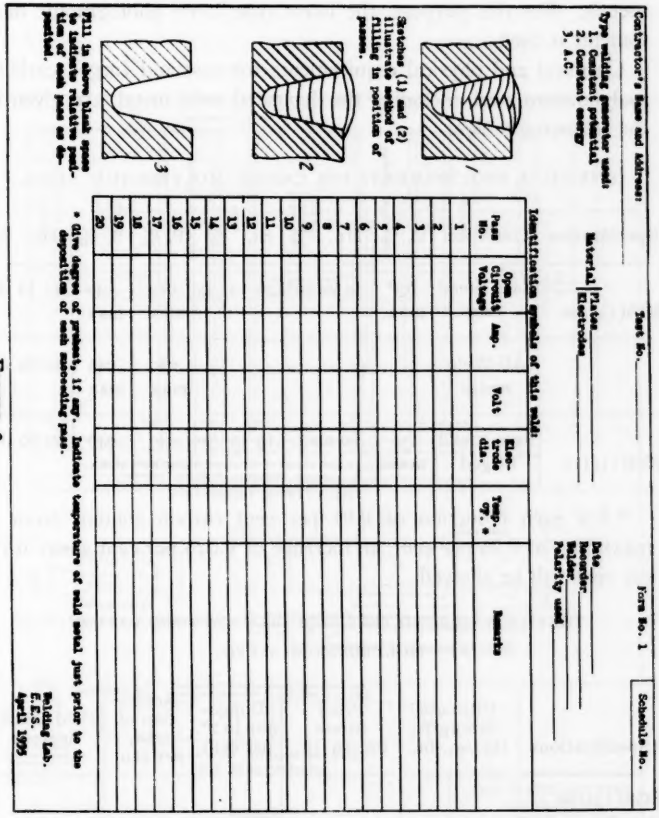


FIGURE 6.

metal, and cast and forged chromium-molybdenum steel and the deposited weld metal.

The question of difference in thermal expansion between the base and deposited weld metal is occasionally encountered. Since under the present specifications, the base material and the deposited weld metal are very similar as regards chemical and physical properties, it would not be expected that the thermal expansion coefficients would be very different. However, when doubt exists, the thermal expansion coefficients are determined for the base and weld

metals. For this purpose, the latest type Leitz photographic dilatometer is used.

Chemical and physical requirements for cast and forged carbon-molybdenum steel, including the deposited weld metal, are given in the following tables:

CHEMICAL REQUIREMENTS FOR CARBON-MOLYBDENUM STEEL.

Specification	Condition	C, %	Mn, %	Si, %	P, %	S, %	Mo, %
SGS(1)110a	Base metal cast	.35* max.	.50 to .70*	.20 to .45	.040 max.	.040 max.	.40 to .60
	All-Weld metal	–	–	–	.040 max.	.045 max.	.40 to .60
SGS(1)111a	Base metal forged	.30 max.	.80 max.	.15 to .30	.040 max.	.040 max.	.40 to .60

* For each reduction of 0.01 per cent carbon content from a maximum of 0.35 per cent, an increase of 0.025 per cent above 0.70 per cent will be allowed.

TENSILE AND BEND TEST REQUIREMENTS FOR CARBON-MOLYBDENUM STEEL.

Specifications	Ultimate Strength lbs./sq. in.	Proof Stress lbs./sq. in.	Elongation in 2″, per cent	Reduction of area, per cent	Cold Bend, degrees
SGS(1)110a Base Metal Cast	70,000 min.	35,000 min.	20	30	120
All-Weld Metal	65,000 min.	40,000 min.	20	–	–
SGS(1)111a Base Metal Wrought	70,000	45.000	30	35	180 inner dia. of 1″

Bend Test.—The bend elongation of the outer fibers of weld shall be 30 per cent minimum.

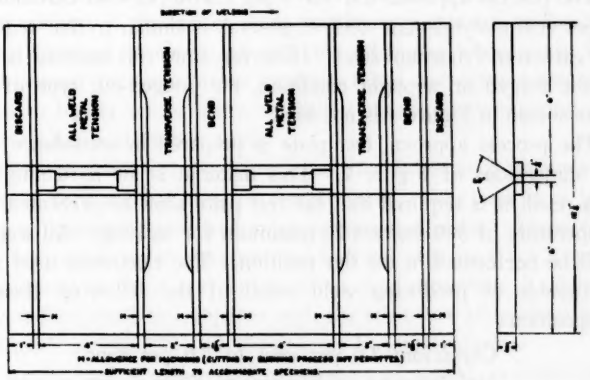


FIG. 1 - LAYOUT OF TEST PLATE

FIG. 2 - ALL WELD METAL TENSION SPECIMEN

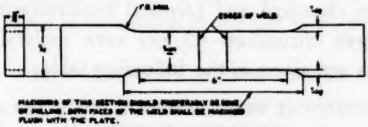


FIG. 3 - TRANSVERSE TENSION SPECIMEN

FIG. 4 - BEND SPECIMEN

FIG. 5 - DIE FOR DEFORMING SPECIMENS UP TO 90°. ADDITIONAL BENDING TO BE DONE FREE

TEST PLATES AND TEST SPECIMENS FOR ALLOY STEEL ELECTRODES

BUREAU OF ENGINEERING, NAVY DEPARTMENT, WASHINGTON, D.C.

April 12, 1935

Index	Group	File No.
6	Y	572

FIG. 7

Transverse Tension Test.—The ultimate strength of the transverse tension specimen shall not be less than 65,000 pounds per square inch.

The process approval test for 4 per cent-6 per cent chromium—.5 per cent molybdenum steel, in general, is similar to that required for carbon-molybdenum steel. However, since this material is used in the forged or wrought condition, the gouged-out type of test plate shown in Figure 4 is not used.

The process approval test plate is prepared in accordance with the dimensions of Figure 7. This material is air hardening and as a result it is required that the test plate shall be preheated to a temperature of 500 degrees F. minimum for welding. All welding shall be performed in the flat position. The electrodes used shall be capable of producing weld metal of the following chemical composition:

Chromium 3.0 per cent to 5.0 per cent
Molybdenum .40 per cent to .65 per cent

The chemical and physical requirements for the 4 per cent—6 per cent chromium—.5 per cent molybdenum base and all-weld metals are given in the following tables:

CHEMICAL REQUIREMENTS FOR 4 PER CENT TO 6 PER CENT CHROMIUM .5 PER CENT MOLYBDENUM STEEL.

Condition	C, %	Mn, %	Si, %	Cr, %	Mo, %	S, %	P, %
Base Metal forged	.15 max.	.50 max.	.50 max.	4.0 to 6.0	.45 to .65	.040 max.	.040 max.
All-Weld Metal	–	–	–	3.0 to 5.0	.40 to .65		

PHYSICAL PROPERTIES.

Condition	Tensile Strength lbs./sq. in.	Yield Point lbs./sq. in.	Elongation in 2″, per cent
Base Metal forged	58,000 min.	25,000 min.	30 min.
All-Weld Metal	–	30,000*	20 min.

* Proof Stress—Stress showing .0001 inch permanent extension per inch of test length after removal of the load.

Transverse Tension Specimen.—Failure shall occur in the stock at a minimum of 58,000 pounds per square inch or in the weld at a minimum of 65,000 pounds per square inch.

Bend Specimen.—Bend elongation 30 per cent minimum.

On account of the higher creep resistance and lower scaling loss of this material as compared with the other low alloy steels, this alloy is used for superheater headers, tubes and other parts subjected to higher temperature conditions than are encountered for the low alloy and carbon steels.

Since the satisfactory performance of this material depends on its creep resistance at elevated temperatures, creep tests have been made of specimens prepared from various test plates. These tests have been made up to temperatures of 1000 degrees F. Likewise, scaling tests of the 4 per cent to 6 per cent chromium .5 per cent molybdenum steel, as compared with the other low alloy steels have been made at 700, 850 and 950 degrees F. temperatures.

A macrograph showing the cross-section of a weld, as taken from a process approval test plate of forged 4 per cent—6 per cent chromium—.5 per cent molybdenum steel is presented in Figure 13.

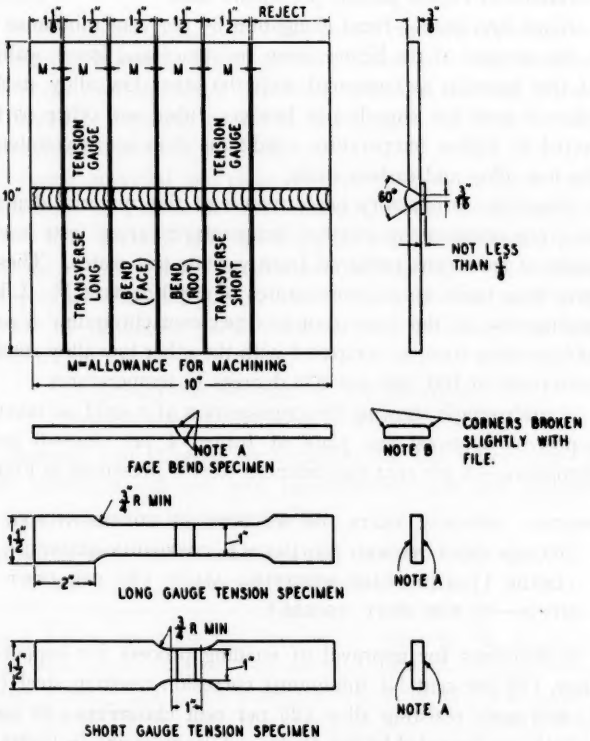
PROCESS APPROVAL TESTS FOR WELDING OF COPPER-NICKEL ALLOY (60 PER CENT NICKEL MINIMUM), CORROSION-RESISTING STEEL (GRADE 1) AND SCALE RESISTING ALLOY (25 PER CENT CHROMIUM—20 PER CENT NICKEL).

Instructions for approval of welding process for copper-nickel alloy, (60 per cent Ni. minimum) corrosion-resisting steel (Grade 1) and scale resisting alloy (25 per cent chromium—20 per cent nickel), are provided by the Bureau of Engineering in leaflet form.

Details of the test plate required for process approval for these materials are shown in Figure 8. As is the case for all other process approval tests for welding, the actual cutting up and testing of the plate are done at the Naval Engineering Experiment Station. It will be noted that a chill strip is provided on the underside of the test plate.

Both face and root bend tests are required. The samples must withstand bending to the full capacity of the bending jig shown in Figure 9. Any crack or opening which results from the bending

ALT 1-CHANGED THICKNESS OF CHILL STRIP FROM $\frac{1}{4}$" TO $\frac{1}{8}$" 5 MAR. 1936



A MACHINE FLUSH BOTH SIDES. DO NOT REMOVE ANY UNDERCUTTING.
B FOR ROOT BEND SPECIMEN, BREAK CORNERS ON BOTTOM EDGES, AND BEND WITH ROOT OF WELD IN TENSION.
C TEMPERATURE OF PREVIOUSLY DEPOSITED WELD METAL SHALL NOT BE OVER 212°F AT TIME OF DEPOSITION OF SUBSEQUENT BEAD OR LAYER.
D PEENING SHALL NOT BE DONE UNLESS IT IS TO BE USED ON THE JOB.
E ROOT OF WELD SHALL NOT BE CHIPPED OUT.

JOINT AND TEST SPECIMENS FOR APPROVAL OF WELDING PROCESS.

BUREAU OF ENGINEERING, NAVY DEPARTMENT. 2331 SK.

FIGURE 8.

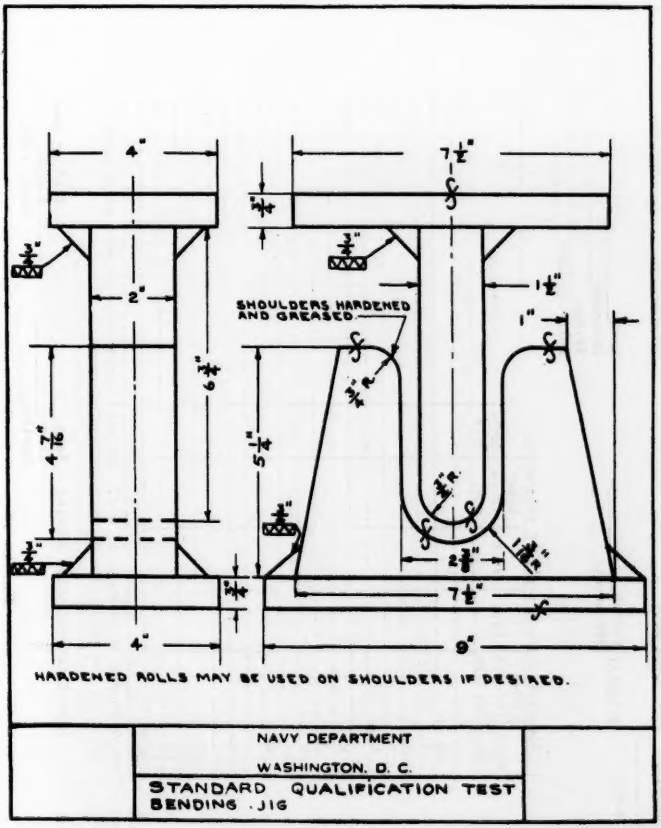


FIGURE 9.

or existed before the bending, and exceeds ⅛ inch measured in any direction, shall reject the specimen. Likewise, both long and short gage tension specimens are required. Tensile values across the weld of 70,000 pounds per square inch minimum for the copper-nickel alloy and Grade 1 corrosion-resisting steel and 80,000 pounds per square inch for the scale resisting alloy are required.

In addition to the tests shown in Figure 8, a visual examination of the test plate is made in order to determine the extent of warp-

Contractor's Name and Address: Test No._____ Form No. 2 Schedule No.

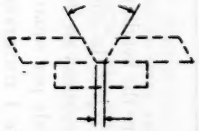
Type welding generator used:
1. Constant potential
2. Constant energy
3. A.C.

Material | Plates_____
Electrodes_____

Date_____
Recorder_____
Welder_____
Polarity used_____

Identification symbols of this weld:_____

Pass No.	Open Circuit Voltage	Amp.	Volt	Electrode dia.	Temp. °F.*	Remarks
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						



Fill in above blank space to indicate relative position of each pass as deposited. Indicate root spacing and the included angle of the scarf.

*Give degree of preheat, if any. Indicate temperature of weld metal just prior to the deposition of each succeeding pass.

Heat treatment after welding - Temp._____
Time _____
Cooling_____

Welding Lab.
E.E.S.
July 1936.

FIGURE 10.

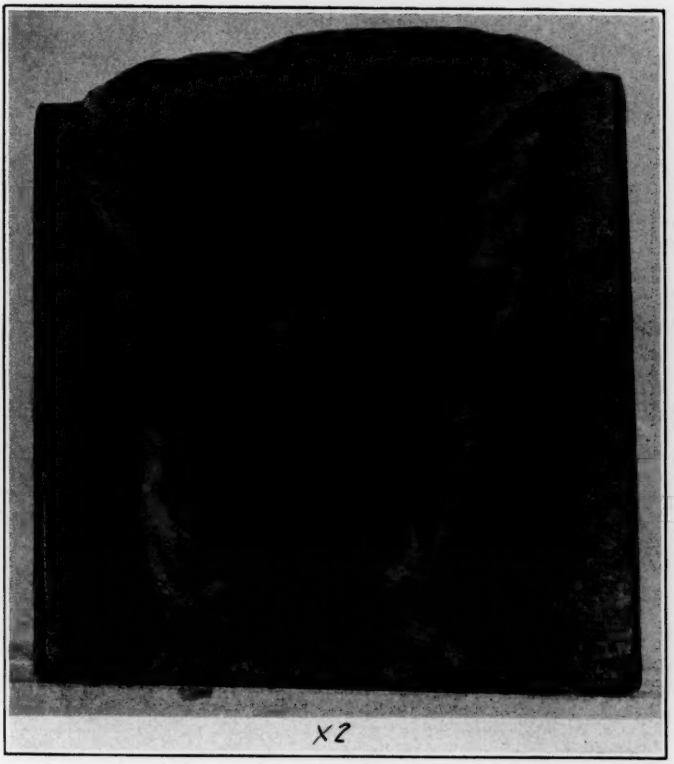


FIGURE 11.

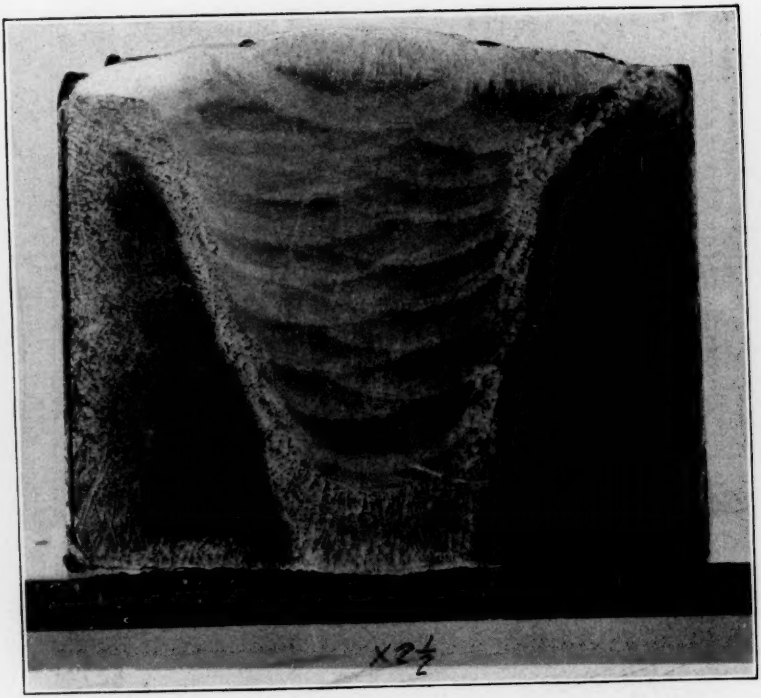


FIGURE 12.

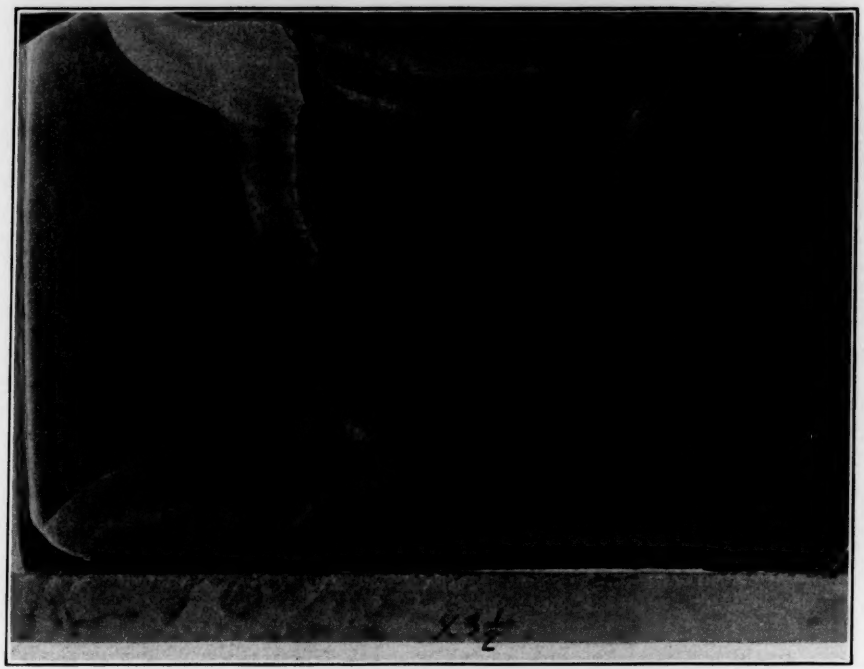


FIGURE 13.

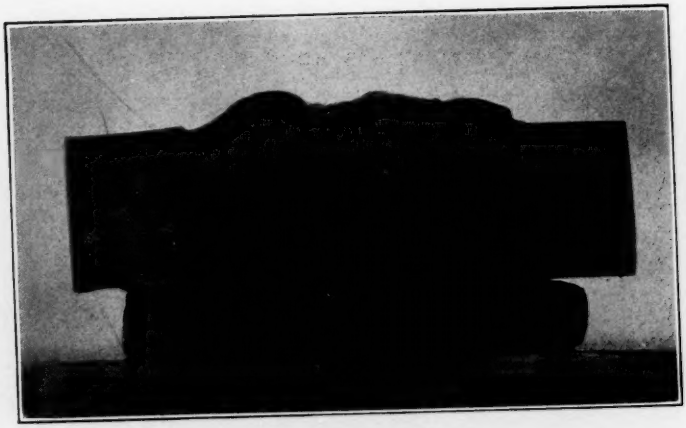


FIGURE 14.

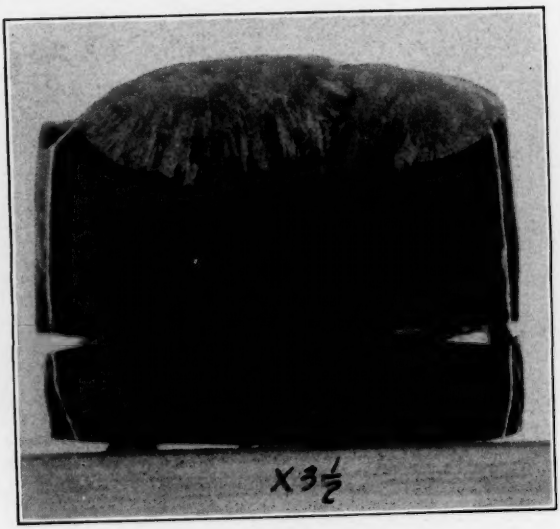


FIGURE 15.

age, undercutting, condition at the root of the weld and general workmanship. A macro and microscopic examination of a cross-section of the weld is made.

Macrographs showing the cross-sections of welds as taken from process approval test plates of copper-nickel alloy and scale resisting alloy are presented in Figures 14 and 15, respectively.

Figure 10 presents a welding form supplied to manufacturers applying to the Bureau of Engineering for process approval for welding copper-nickel alloy, corrosion-resisting steel (Grade 1) and scale-resisting alloy. This form is filled in by the manufacturer and forwarded to the U. S. Naval Engineering Experiment Station with the welded test plate. These data form a part of the record of the test.

PREPARATION OF TEST SPECIMENS.

All test specimens are cut from the process approval test plates by means of a power hack saw. The saw used for this purpose is designed so that the blade is maintained in the horizontal position regardless of the depth of the cut. A coolant is supplied to the blade while cutting. Rectangular tension and bend specimens are shaped in a shaper, the test lengths of the tension specimens being formed in a milling machine. In preparing bend and tension test specimens of rectangular cross-section, care is exercised so as not to remove the effects of undercutting. Tension specimens .505 inch in diameter are provided with threaded ends. Specimens for macroscopic examination are ground on a surface grinder followed by a metallographic polish in the usual manner. The alternate method of longitudinal and circumferential polishing of endurance test specimens was previously mentioned.

ELECTRODES.

Before it is possible to submit a welded test plate for process approval, it is necessary that satisfactory electrodes be available for the purpose. The procedure for testing electrodes for acceptability by the Navy is similar to the process approval tests for welded assemblies in so far that a test plate is prepared for examination and test. However, the testing procedures and specifications for elec-

trodes are entirely independent of the process approval tests for welded assemblies, the primary purpose of the latter being to determine the suitability of the welding practice and technique.

Actually, process approval tests of welded assemblies have contributed considerably to the knowledge of the electrodes most suitable for specific purposes. This was particularly true in the early stages of the development of electrodes.

Approval tests for electrodes provide information as to the following:

Composition of core.
Nature of electrode coating.
Preheat required, if any.
Polarity.
Size of electrode for specific purpose, depending on joint design and mass.
Approximate current requirement.
Technique and manipulation in various positions.

It is desirable that electrodes deposit material of approximately the same chemical composition as the base material to be welded. For the materials previously described this has been accomplished in a large measure. At the present time, the bronzes, deposited by electro-deposition, present the most notable exception to this rule. Possibly with further development, electro-deposition of bronze material more similar in chemical composition to that of the base material will become practicable.

NOTES.

INDEX TO NOTES.

WELDED BOILER DRUM PRACTICE.
—An extract from Round Table Conferences, Combustion, New York, N.Y., October, 1936.

PRACTICAL ASPECTS OF HULL WELDING.
—By F. A. Miller, Motorship and Diesel Boating, New York, N. Y., August, 1936.

(*a*) ON THE PROPERTIES OF METAL DEPOSITED IN ARC WELDING WITH DOMESTIC ELECTRODES.
—Abstract of article by Tachu Naito and Akira Tsuruta.

(*b*) ON THE ELECTROMAGNETIC PROPERTIES OF THE METAL DEPOSITED IN WELDING.
—Abstract of article by Minoru Okada.

(*c*) STRENGTH OF COMBINED JOINTS, RIVETS AND WELDS.
—Abstract of article by Tachu Naito, Akira Tsuruta, and Kazuo Minami.
—National Research Council of Japan, Japanese Journal of Engineering, Abstracts, Vol. XIV, Tokyo, Japan, 1936.

WELDING RESEARCH.
—Shipbuilding and Shipping Record, London, England, 30 July, 1936.

WELDED WARSHIPS.
—Shipbuilding and Shipping Record, London, England, 6 August, 1936.

ELECTRIC ARC WELDING OF BRASS AND BRONZE.
—The Marine Engineer, London, England, September, 1936.

WELDING METALS WITHOUT FUSION BY MOLECULAR SHOCK.
—(A. H. Allen, in Steel, Vol. 98, No. 25, June 22, 1936)—Mechanical Engineering, New York, N. Y., November, 1936.

WELDED EVAPORATORS.
—The Engineer, London, England, September 18, 1936.

EDITOR'S FORUM.

In presenting this number of the JOURNAL to the Society, the Editor trusts that he will be forgiven for devoting the entire space in one issue to the subject of Welding. His feeling was that the art has developed so rapidly, and has been so completely accepted into the industrial scheme of things, that not many engineers have taken time out to take stock of the development. It seemed logical, therefore, to present a resume of accomplishment where this had been manifested in naval engineering endeavor. Acting for the Council of the Society, he takes this opportunity to express deep appreciation to the seven authors who contributed graciously to meet their parts in the symposium, for they are all "full-time" men in their own lines, and men who have developed with, and definitely progressed the development of the art. Where "Stop! Look! and Listen!" signs have been posted here and there through the various discussions, they should be heeded and given due consideration, for Welding is still in its infancy, maturing by leaps and bounds it is true, but still imperfect—and sometimes dangerous.

WELDED BOILER DRUM PRACTICE.

An extract from "Round Table Conferences," Combustion, New York, N. Y., October, 1936.

At the Pittsburgh Round Table Conference on September 4, E. R. FISH, Chief Engineer of the Boiler Division, The Hartford Steam Boiler Inspection & Insurance Company, attributed growth of welded drum construction to the trend toward higher steam pressures and temperatures, for even with relatively small drum diameters plate thicknesses approached the practical limit for riveted construction, which is about 2 inches. Also, the demand for large capacity units necessitated very long drums, for which riveting was impracticable. He reviewed the transition stage of forged drum construction, which, because of the expense involved, gave way to fusion welding as soon as it was demonstrated to the satisfaction of the A. S. M. E. Boiler Code Committee that this practice, with certain prescribed safeguards, was acceptable. This was just five years ago, and today the substitution of welded for riveted or seamless construction has become general for moderate as well as for high pressures in this country. Plates up to 5 inches thick and 35 or 40 feet long are now pressed and welded.

Not only are the seams welded, but it is also the practice, under carefully prescribed rules, to attach by welding the outlet nozzles and any needed reinforcement.

He pointed out that riveted joints in boiler drums have always been subject to leakages and other troubles such as cracking between rivet holes, which have caused many major failures. On the other hand, welded drums are absolutely tight and there are no discontinuities to cause concentrations of stresses of unknown distribution and magnitude. Boiler insurance companies are strong proponents of welded construction and do not hesitate to afford insurance on boilers of this type. Moreover, there is little difference in the relative costs of riveted and welded construction.

Although the A. S. M. E. Boiler Code does not sanction the welding of other than the cylindrical parts of a boiler, it now has a subcommittee charged with the study of the extension of welding to other features of boiler design such as staybolts, water-wall and superheater tubes, braces etc.

A. J. Moses, of the Hedges-Walsh-Weidner Division of Combustion Engineering Company, at Pittsburgh discussed welded boiler drum practice from the standpoint of accepted materials, methods of construction and present trends. At present the A. S. M. E. Boiler Code approves the use of two grades of modified carbon steel of 65,000 and 70,000 pounds per square inch minimum tensile strength, these steels differing from the 55,000-pound firebox steel in that the carbon and manganese contents are higher, being limited to 0.35 per cent and 0.9 per cent, respectively. These steels are now in general use in the construction of welded high-pressure boiler drums.

Boiler plates up to 5-inch thickness are now being employed and where the thickness exceeds 2 inches, a normalizing heat treatment is applied to the flat plates before forming, for grain refinement. Also, a subsequent drawing treatment is sometimes given to facilitate the forming operation when this is performed cold. The shaping of these heavy plates is done under hydraulic pressure, and this necessitates two longitudinal seams. Since intermediate girth seams are not desirable the shells are composed of two plates each formed to approximate half circles. Shells exceeding 40 feet in length have been thus constructed.

Plates of unequal thickness are frequently employed in such drums, the heavier section being designed for areas to be perforated with tube holes and the lighter plate for unperforated sections or those having greater tube hole ligament efficiency. In such cases the heavier plate is tapered by machining to the thickness of the lighter plate. This planing, together with machining of the weld grooves, is usually done after the plates have been formed into half cylinders.

The electric metallic arc method of welding with heavily coated electrodes about ¼ inch diameter is the accepted practice. Fillet welding is permitted only in the welding of nozzles, reinforcements and attachments. All welding is done in the down-hand position, the drum being slowly rotated to accomplish this when the heads are being welded to the shell. The weld metal is deposited in the grooves in relatively thin layers. Inasmuch as the process leaves a heavy slag coating over these layers it becomes necessary to clean thoroughly the slag from each layer before depositing the succeeding layer.

In finishing double-butt welds a small reinforcement of deposited metal is added to both sides of the plate and this is subsequently chipped off and the surfaces ground practically flush with the plate. With longitudinal seams, attached samples continuous with the joint are welded for checking against standard requirements.

Following the X-ray examination, completely welded drums are thermally stress-relieved, the drums being gradually brought up to a temperature of 1100 to 1250 F., held there for an hour per inch of thickness and the furnace cooled to about 500 F. before removal.

At present there is a demand for a reliable and economical extension of non-destructive testing to greater thicknesses and also for the approval of higher tensile steels. Some very promising preliminary fatigue tests have already been made on welded vessels fabricated of special steels of tensile strengths up to 85,000 pounds per square inch minimum. Present data indicate that limitations in this respect will have to do with ductility requirements of the base materials.

Dr. D. S. Jacobus, Advisory Engineer of Babcock & Wilcox Company and Chairman of the A. S. M. E. Boiler Code Committee, opened the discussion on this topic at Philadelphia. He reviewed the successive steps leading to the formulation of rules for fusion welding by the Boiler Code Committee and tests conducted to verify or assist in establishing certain provisions.

The matter was first brought before the Committee in March, 1920. The first set of rules, promulgated in 1927, was limited in its application to unfired pressure vessels and specified low working stresses for the fusion welded joints. Subsequent tests that demonstrated the dependability of properly made fusion welds, and the development of suitable X-ray apparatus to permit the examination of joints in steel plates up to 3 inches, led to the publication in 1930 of proposed specifications for the fusion welding of drums or shells of power boilers and shortly thereafter a complete review of the rules for fusion welding of unfired pressure vessels. The rules affecting boiler drums and shells were adopted in July, 1931. These rules do not cover all parts of boilers that might be fusion welded, but special rules have been and are being added from time to time to cover more fully all types of construction.

In formulating the A. S. M. E. Boiler Code rules for fusion welding every precaution was taken to secure safety and all welds are required to be stress-relieved at a temperature of from 1100 to 1200 F. for a period proportioned on the basis of at least one hour per inch of thickness. This eliminates a troublesome element involved in the A. S. M. E. Unfired Pressure Vessel Code and in other codes covering unfired pressure vessels, such as the Joint A. P. I.-A. S. M. E. Code for Petroleum, Liquids and Gases which sanctions the building of certain vessels without stress-relief and makes it necessary to provide rules to cover the vessels that need not be stress-relieved. The method of examination of welded joints by the X-ray has been a major factor in securing safety and in establishing confidence in the use of welded boiler drums.

To give an idea of the rapid acceptance of fusion welding, which has practically supplanted riveted construction during the last five years, Dr. Jacobus quoted figures from eleven companies showing that approximately 7000 boiler drums and pressure vessels have been fabricated in which the main joints were X-rayed. These represent about 800,000 linear feet of welded joints in shells ranging up to 4⅞ inches in thickness. In the Boulder Dam project, 270,000 feet of film was used for the examination of the joints in the welded penstocks.

The use of higher tensile strength plate has been increasing. While plate of 55,000 pounds per square inch minimum strength has long been standard for stationary boiler construction now a large amount of 70,000-pound plate is being used, particularly for high-pressure drums. This is an open hearth silicon-killed steel with slightly increased carbon content. A weight saving of a little over 25 per cent may thus be obtained.

German practice as explained in a paper by DIPL. ING. E. LUPBERGER, Director of the Association of Owners of Large Boilers, Berlin, has practically discarded riveted drum construction for new boilers. For pressures up to 850 or 900 pounds, gas or electrically welded drums are usually employed, whereas for pressures in excess of this forged drums of steel having a tensile strength up to 100,000 pounds per square inch are employed. Because of this high tensile strength, thinner wall thickness, hence lighter drums, are possible. Forged drums up to 66 inches diameter and 60 feet long have been made.

It is customary not only to stress-relieve the welded drums at about 1100 F. but to normalize them at about 1700 F. They are being made of low-carbon steel or an alloy steel containing 0.3 per cent molybdenum and of 70,000 pounds per square inch tensile strength. Fusion-welded drums are usually subjected to X-ray examination, the X-ray tubes being placed within the drums in order to have the rays normal to the plate. Gamma radiation

is also employed to some extent and magnetic powder is used to detect small cracks. X-ray voltages up to 200,000 are available. Furthermore, all connections to high-pressure drums are made of small diameter and in multiple, where required, so that reinforcement is not necessary. Welding is applied to connections only as a means of securing tightness and not for strength.

PRACTICAL ASPECTS OF HULL WELDING.

By F. A. Miller.

Motorship and Diesel Boating, New York, N. Y., August, 1936.

Welded ships are no longer synonomous with experimentation, yet some die-hards in the marine construction business will not relinquish their adherence to riveted construction. The near future will, however, see them forced to come around to this more practical means of assembly.

Realization of the practical simplicity of welding has been retarded by the injection of many unnecessary complications on the part of equipment makers. First, is the matter of electrodes, the manufacture of which is a big industry today: The manufacturers are apparently interested in keeping this a complex subject. A coated rod plus sales talk goes to the ship yard at 12 cents to 15 cents per pound. Bare rod, in most cases preferable, costs only six or seven cents.

We are invariably reminded that coated rods have a tensile strength of 60,000 pounds or more, the words "tensile strength" being very impressive. Common sense bespeaks it as illogical to use a 60,000 pound wire on a 40,000 pound plate. This racket, or "technical aspect," is, however, becoming better understood, and with welding no longer a mystery, the purchasing agent is beginning to think more practically.

The forced sales on rod have likewise obscured the value of carbon arc welding, which is one of the most practical forms of good ship construction today. There has been also flagrant overselling on welding machines themselves. Most every plant that you look into will be operating machines of a size several times in excess of requirements. Plant operators should be more practical and less gullible when purchasing equipment. Plain unadulterated reasoning power is the basis of all smart buying in this field.

Hulls, some ten years ago, in which modern welding was employed, were nothing to brag about. Today's welded hulls can be as smooth as glass. Only one thing has been responsible for these results. It is experience, not theory.

A regrettable fact is that our technicians have allowed European nations to lead the way in this type of construction, especially in the smaller steel vessels. The standardized small power boats built abroad today are steel, welded. Wooden craft are obsolete. It seems that we have only achieved complete success on welded vessels here when there has been a "run" on a certain type. After a quantity of this type has been produced, suiting the owner, they are accepted and recognized. It is unfortunate that we should have to go through these stages to overcome prejudices. More surprising today is to see the number of intelligent people who are firm believers in the superiority of wooden construction over metal for the smaller type of crafts. Most of the steel manufacturing companies will gladly give intelligent cooperation with the buyers in an endeavor to provide the right materials.

My own experience covers some 210 all-welded hulls, the first being constructed in 1908 with a home-made machine. It has been my privilege to

watch this industry grow from the very ground up to its present day proportions, both here and abroad. This experience has enabled me to arrive at a few deductions, which follow:

The best ship plate for welding purposes is a mild steel with a carbon content averaging around .012 and under no circumstances exceeding .018. If this plate is to form a tensile member, it is best fused with a coated rod having a carbon content considerably higher than .020. If it is a non-tensile member, which means a mild steel of 40,000 pounds tensile strength or less, the best results can be obtained with a bare rod. The diameter of the rod should be 10 per cent to 25 per cent less than the thickness of the plate. The reason for having the high carbon content in the rod is that it will burn proportionately slower and give a decidedly better penetration than will the low carbon rod, permitting the arc to concentrate most of the heat and melting the wire rather than driving it into the base metal.

One of the most serious problems is to secure coordination between the proper material, and the human element. Invariably the operator who has been brought up on coated electrodes prefers them for every purpose. The operator accustomed to bare rods or carbon welding, likewise, tries to adapt these to his routine work. Very few plants, I have found, maintain a rigid supervision over their employees in this respect, and in this laxity lies the greatest weakness of welding today.

No ship can be properly built without at least five types of electrodes, yet the average vessel under construction today is being assembled with one type of rod supplied in two sizes. Fifty per cent of all ship welding can be successfully accomplished with a carbon arc.

Another difficulty in plant management relating to welding operators is the control of heat. Each individual operator is almost without exception permitted to operate at a voltage and amperage which he believes correct, which in almost every case, if investigated, will be found to be the heat at which he can operate the most rapidly and easily. A table which can be used successfully and one in which far lower than the average heat is used is as follows:

For 10 gauge material—150 amperes and approximately 40 volts
For 3/16 steel—200 amperes and approximately 45 volts
For 3/8 plates—225 amperes and approximately 50 volts

I have frequently seen as much as 300 amperes used in the fabrication of 12 gauge sheets. While the penetration may be approximately correct, the post annealment is such as to inflict a tremendous stress on the joint. I have seen two small craft, each 40 feet in length, laid down side by side. On one the welders, who were all good men, were allowed to operate their machines to suit their own whims. On the other hull the power was scientifically fixed, and the current on each job was checked through individual meters. The complete current cost of welding the first hull was $62. The cost of welding the latter was about half as much. After one year's service, the first hull had three bad breaks or rips along the bilge line. The second hull has never given any trouble whatsoever. Yet during its construction the welders were constantly demanding "more heat."

The point I am trying to bring out is that even if you are not at all familiar with welding, but are doing welding work in your shop, don't be guided by the opinions of your workmen. Do a little figuring yourself. There is nothing in the world that logic and horse sense will apply to any better than this subject. Don't be confused by long names and technical gymnastics.

(a) ON THE PROPERTIES OF THE METAL DEPOSITED IN ARC WELDING WITH DOMESTIC ELECTRODES. [Journal of the Institute of Japanese Architects. Vol. 48, No. 584 (1934).] Abstract of article by Tachu Naito and Akira Tsuruta.

The authors present in this paper some observations from their studies of the metal deposited in arc welding with domestic electrodes commonly used in building construction in Japan. The studies consist of measurements of the physical properties and the possible effects of annealing on the physical properties. Ordinary structural steel was tested in parallel for comparison with the metal deposited by the electrodes.

The electrodes used in the test, which were coated electrodes, and which were designated A, B, C, were supplied by three representative manufacturing companies. The tests consisted of tension test, an impact test in which the Charpy impact machine was used, and repeated impact test in which the Mohr repeated impact machine was used.

The test pieces were obtained, by shaving and milling, entirely from the metal that was deposited in many layers on a steel plate. The test pieces for the structural steel were obtained from common round bars milled to size and dimension to conform with the foregoing specimens.

The conclusions are summarized as follows:

1. The tensile strength of the deposited metal is about 47 kg/mm^2 without annealing and about 43 kg/mm^2 with annealing. The yield point is about 60 per cent of the ultimate strength, the modulus of elasticity being about 2,000,000 kg/cm^2. The elongation is from 10 to 15 per cent in 100 mm gauge. The properties are similar to those of mild steel with the exception of the elongation, which is less.

2. The resistance of the deposited metal to impact is from 2 to 4 kg m which is considerably less than the value for mild steel, which is about 22 kg m.

3. The result of the repeated impact test indicates that some of the deposited metal has practically the same strength as mild steel. When, however, a mild steel fails at 8000 blows, the probable average failure for the deposited metal may be around 4000 blows.

For the second report, the authors obtained the following results, owing to the additional experiment:

4. According to the competence of the welder, the tensile strength of the metal deposited from the same electrode showed a range in variation of 20 per cent between the highest and the lowest.

5. The difference in range in the tensile strength of the deposited metal as affected by the direction of the external force and weld beading is about 10 per cent, which it may be stated will vary as the result of other conditions.

(b) ON THE ELECTROMAGNETIC PROPERTIES OF THE METAL DEPOSITED IN WELDING (IN JAPANESE). [Tetsu-to-Hagane, 20 (1934) 535-547, with figs., photos, and tables.]—Abstract of article by Minoru Okada. The metal deposited from commercial and specially prepared electrodes were examined, and their electromagnetic properties, their mechanical properties, and the changes in these properties, both before and after aging and annealing were studied with the following results:

Although the electric resistivity of the metal deposited from the bare low carbon electrode was comparatively small, its mechanical properties were inferior to that deposited from the covered electrode.

In the case of magnetic circuit welding, the deposited metal had high permeability, low hysteresis loss, and high electric resistivity. For this purpose it was possible to use electrodes that had a suitable coating of manganese and silicon. The manganese itself does not directly affect the magnetic property of the deposited metal, all it does being to minimize the contamination of the deposited metal by air.

Although the metal deposited from the phosphorus coated electrode was slightly better than that from the bare electrode, it was so brittle that it was readily cracked by a light touch of the hammer. Except under the critical quantity of aluminium, the iron aluminium alloys were like the iron phosphorus alloys.

The magnetic characteristics of the deposited metal were greatly affected by the cooling rate of the metal, especially, below 550 degrees C.

The metal deposited from the manganese-coated electrode showed higher tensile strength, while that from the silicon coated electrode showed higher impact resistance. The metal deposited from the electrode coated with silicon and manganese showed superior mechanical properties.

Although the grains of the metal deposited from the silicon coated electrode were large, upon addition of manganese to the electrode, they became of fine size. Until the quantity of phosphorus in the deposited metal reached 2.5 per cent, the characteristic sharp needle-like structure was observable.

Low carbon steel welded by the atomic hydrogen welding process possessed good electromagnetic and mechanical properties, although its magnetic characteristics showed considerable aging effects.

Silicon coated electrodes were rarely employed in the electric arc process owing to the constant dropping of large globules from the electrode. Despite certain difficulties, however, it was possible to use the silicon and manganese coated electrode.

(c) STRENGTH OF COMBINED JOINTS, RIVETS AND WELDS (IN JAPANESE). [Journal of the Institute of Japanese Architects. Vol. 48, No. 584 (1934).]—Abstract of article, by Tachu Naito, Akira Tsuruta, and Kazuo Minami.

In the present paper the authors treat in brief their experiments on the strength of joints prepared by the combined use of rivets and welds. First, the authors obtained on the one hand the unit strength respectively in test pieces made of rivets and in those of welds, while on the other they obtained the strength of the pieces of rivets and welds combined in a variety of ratios. Second, the authors calculated the strength of the combined pieces based on the unit strength, after which they tried to obtain the necessary data required for practical designs by comparing the calculated strength with the experimental strength.

Taking the testing machine into consideration, the test pieces were prepared so as to be almost equal in their strength to eight rivets of 12 mm diameter.

With the present experiment, the following results were obtained:

(*a*) The unit strength proved to be almost the same, irrespective of the number of rivets and the length of the welds.

(*b*) The strength of the combined pieces is 7/8 (87 per cent) of the sum of the component strengths of the rivets and welds.

(*c*) When the component strength of the rivets and welds is nearly equal, a combined strength of 93 per cent is obtained, which is almost the maximum.

(*d*) When the welds were placed nearer the joint, the strength proved more effective.

The authors are now prosecuting further studies, the result of which may require certain modification to those obtained in the present experiment.

(a), (b), and (c) are taken from the National Research Council of Japan, Japanese Journal of Engineering, Abstracts, Vol. XIV, Tokyo, Japan, 1936.

WELDING RESEARCH.

Shipbuilding and Shipping Record, London, England, 30 July, 1936.

The use of welding both in the construction of a ship and of its machinery is becoming of ever-increasing importance and a careful survey of modern shipbuilding and marine engineering practice reveals the extent to which welding is employed in preference to other available methods of construction. In spite of all this, however, there is still a certain amount of reluctance to employ welding for those parts which are subjected to complex and unstable stress conditions such as the strength portions of the hull and those parts of the machinery which are subjected to the effects of high pressure and temperature. The reasons for this are not far to seek, although whether they are justifiable is certainly open to question. Thus, the quality of the finished weld depends largely upon the human factor and careless or hasty work cannot be expected to give good results. Again, the composition of the electrode, the nature of the electrode covering employed (if any) and also the quality of the steel plates being welded, has a profound effect upon the composition and structure of the joint; while, probably most important of all, the high temperatures developed during the welding process may cause fundamental changes to occur in the strength and elastic properties of the materials as compared with those in the pre-welded state. These and other important facts are revealed in the "Second Report of the Welding Research Committee" of the Institution of Mechanical Engineers, which was presented and discussed at a recent meeting of the Institution.

It is of interest to recall that the committee was formed primarily to investigate the suitability of welding as applied to pressure vessels such as boiler shells, but in so far as their investigations as described in the report have been carried out on various grades of steel plate, all of them ½ inch thick, it is apparent that when due allowance is made for the quality of the original plate, the results give a valuable indication of the possibilities of welding as applied to other applications of steel plates such as shipbuilding and the fabrication of machinery framing. Within these limitations, a study of the report reveals the fact that even under the best conditions as, presumably, must be associated with laboratory work, the nature and quality of the welded joint is liable to considerable variation. This, indeed, is admitted in the report itself, and was dwelt upon by a number of those who took part in the discussion. The points, it may be men-

tioned, were subsequently subjected to X-ray examination and it was revealed that small centers and inclusions were found in all except the best welds, and it is stated that these may have an important effect upon the fatigue range of the weld. It is of interest to note that the conditions shown by photo-micrographs were confirmed by the X-ray photographs. The joints, some of which were subsequently heat-treated, were then subjected to short-time tensile tests, to long-time creep tests at temperatures from about 250 degrees to 575 degrees C. (482 degrees to 1,067 degrees F.), to Izod impact tests, to various embrittlement tests and to cold bend tests, the results of all of which are given in the report together with graphs of the various data obtained.

Of the various conclusions arrived at, mention may be made of the opinion that at boiler temperatures, as distinct from superheat temperatures, no serious difficulty due to creep need be apprehended at the normal working stresses of boilers, neither is there any fear of that type of brittleness which impact tests indicate causing failure. On the other hand, repeated-stress tests show definitely that the welds examined have fatigue ranges less than that for unpierced steel plates of the same tensile strength as the weld. Further, the investigations show clearly that it is important to select a suitable type of electrode and welding technique in order that cavities and inclusions may be reduced to a minimum, while definite control in the method of welding is of fundamental importance in order to avoid imperfect fusion. Space will not permit of a detailed summary of the discussion in which, among others, Professor Haigh, whose 1934 I. N. A. paper will be remembered, and Dr. S. F. Dorey participated. It will be found, however, in the *Proceedings* and merits very careful study, as indicating both the possibilities and the limitations of the welded joint.

WELDED WARSHIPS

Shipbuilding and Shipping Record, London, England, 6 August, 1936.

At the present time it is particularly interesting to note that the German Navy, after taking to all-welded men-of-war with the greatest enthusiasm, has now abandoned the practice as a result of experience. The first of their 10,000-ton pocket battleships, the *Deutschland,* was all-welded, and she saved a remarkable amount of weight by that means. The later battleships are not. The same applies to the cruisers and destroyers which have recently been completed or are now under construction. The German experience has been that, especially when the ship is pounding against a heavy sea, the plates of an all-welded ship have an unfortunate tendency to fail completely. This failure is not in the weld itself, but in the plates a little distant from the joint, where the metal has apparently been affected by the heat used in the operation. The fact that they have abandoned the all-welded ship certainly does not mean that they have abandoned the welding principle, for they still use it very largely, although with more discretion. The advantages claimed for it when it was first introduced still hold good and several others have been discovered. Ever since the naval clauses of the Treaty of Versailles have been "washed out" the saving of weight is most important in a warship, but it must not make her so rigid that she tends to crack in a seaway. At the present time there is a good deal of discussion as to whether it is best to have the vertical joints welded and the horizontal ones riveted, or vice versa.

ELECTRIC ARC WELDING OF BRASS AND BRONZE.

The Marine Engineer, London, England, September, 1936.

Many marine engineers are under the impression that the welding of brass and bronze is confined to the oxy-acetylene process. This is not the case and, in fact, these materials were successfully welded as long ago as 1920. Since then, this branch of arc welding has progressed considerably and offers several advantages, it is considered, over the gas-welding method. It is in many cases considerably faster, especially on heavy sections, and can usually be applied direct to the job without the necessity for preheating a large volume of metal. Moreover, as the heat is concentrated, there is less likelihood of cracks developing from undue contraction stresses.

Arc welding finds application to numerous jobs, among which may be counted the repair of faulty castings, building up new surfaces on propellers, valves, impellers and blades. It is used very successfully for the repair of bells owing to the fact that the "ring" is not impaired and the weld can hardly be distinguished from the cast metal. Electrodes are also available for welding phosphor bronze and pure copper.

One of the main difficulties in brass and bronze welding lies in the variety of compositions which are met with, and for this purpose Welding Supplies, Ltd., Charlton S. E. 7, manufacture a range of four electrodes in addition to one for welding copper. A direct current welding plant is essential to produce a satisfactory weld owing to the instability of the arc. The actual welding of brass and copper must be carried out on the flat. Vertical and overhead welding are not considered practicable with these materials. The procedure is similar to that used with weld steel electrodes, although the metal transference through the arc is quite different and the metal is carried down in fairly large globules at regular intervals of about one second.

WELDING METALS WITHOUT FUSION BY MOLECULAR SHOCK.

A. H. Allen, in Steel, Vol. 98, No. 25, June 22, 1936.—Mechanical Engineering, New York, N. Y., November, 1936.

This method was developed by Antonio Longoria, of Cleveland, Ohio, and is said to be successful. It is said that two pieces of 28-gauge stainless steel have been welded at a temperature not exceeding 700 F. and the weld showed a tensile strength within 1/10 of 1 per cent of that of the base metal. It is also stated that Longoria has welded 16-gauge galvanized-steel sheets at the rate of 64 feet per minute. No pressure is required on pieces to be butt-welded. The edges are simply sheared and placed together before running through the equipment which does the welding. The underlying theory is that metals like all matter are composed of molecules held together by molecular attraction which involves electric charges on the molecules. Longoria reasoned that if it were possible to break down this molecular bond in two pieces of metal while they are in contact, then they would weld together without fusion. This bond is said to be broken by the proper application of high-frequency electric currents. Photomicrographs of welded material after etching are shown in the original article.

WELDED EVAPORATORS.

The Engineer, London, England, September 18, 1936.

Four evaporators constructed by G. A. Harvey and Co. (London), Ltd., of Greenwich Metal Works, S. E. 7, to the order of Tate and Lyle, Ltd., Plaistow, are claimed to be the largest welded pressure vessels so far made to Lloyd's Class (1) Code. Designed for a pressure of 250 pounds per square inch on 11 feet diameter, they should be of considerable interest to manufacturers engaged in work of this kind, and we are indebted to Mr. H. B. Fergusson, the manager of G. A. Harvey's heavy construction shops, for the following particulars. All four evaporators are very similar and it will suffice to describe No. 1, which has an internal diameter of 11 feet, and a total height of 26 feet 9 inches. It is composed of two shells, each 10 feet 4 inches high, a domed bottom just over 3 feet deep, and a domed cover of the same depth. The bottom shell is known as the Calandria section, and has two tube plates, each in one piece and each 1 inch thick, welded with fillet welds inside and out to the shell at about 7 inches from each end. There are 1792 tubes of 1½ inch bore, No. 8 gauge, and 9 feet 0½ inches long, connecting the two tube plates. The tubes protrude ¼ inch above the plates, and each is welded round. A central, 2 feet 6 inches diameter, tube, between the plates, is ⅞ inches thick. The thickness of the Calandria shell is 1 15/32 inches, and that of the top shell 1 1/8 inches. The bottom and top dished and flanged ends are 1⅜ inches thick, have an 8 foot radius of dish and a 12 inch corner radius. Both shell plates are in one piece, with one longitudinal seam, the ends also being made from one plate. Before dishing and flanging, the plates for these ends had a diameter of 13 feet 5½ inches. They were of the maximum width that can be rolled in England.

There are five main wells on each vessel—the two vertical welds of the bottom and upper shells and three horizontal circular welds, one connecting the two shells and the other two joining the top and bottom ends of the shell. The working pressure of the Calandria section of the vessel is 250 pounds per square inch, and the test pressure was 375 pounds per square inch. The upper shell and the two ends are subjected to 190 pounds per square inch, and were tested to 285 pounds. The weight of the completed vessel is 48 tons. All four vessels were completely fabricated in the shops and lifted 100 feet from the ground in Tate and Lyle's new refinery at Plaistow. They were not only built to conform with Lloyd's Class (1) Code for welded pressure vessels, but were also independently surveyed by the Vulcan Boiler and General Insurance Company, Ltd., to the A. S. M. E. Code.

Rather more than the usual number of test pieces of the welding were required as coupon plates were welded to both ends of the longitudinal seams. On each coupon plate the following tests were made:—One pull across the weld, two bend tests, one an inner bend and the other an outer bend, until the limbs were parallel, which gives 60 per cent elongation of the outer fibers; two Izod tests, one all-weld metal test. Four micros, and one macro were also taken. All the main seams were naturally X-rayed at the works, no inclusions, lack of penetration or the presence of porosity being allowed.

The heat treatment of the longitudinal seams of the shell was a fairly simple matter, but that of the circular seams after the vessels were completed was difficult. A special gas ring was made on which the gas nozzles

were placed about 1 inch apart, all the way round the 35 feet of seam, there being eight sections to each ring, with its own pressure, air, and gas supplies. The gas was made to impinge on a refractory concrete lining, which, when white hot, reflected the heat back on to the weld. The elements of four pyrometers were tack welded to the inside of the weld, and the readings were recorded every five minutes. Each of the eight gas ring segments was controlled by valves so that the temperature could be adjusted all the way round the seam.

It was considered inadvisable to heat treat the whole vessel in the work's furnace, as the great weight of tubes in the Calandria section would have caused considerable distortion. Long experience with tube plates welded in shows that it is unnecessary to heat treat these plates. At the request of the insurance companies, lacing straps were omitted. The welded seams were all given a thorough hammer test with a 7-pound hammer, at full swing, while the maximum test pressure was on, when no leaks developed on any of the welded seams.

One or two details of manufacture may be added. The edges of the flanges of the dished and flanged ends were all machined to the same thickness as that of the shell on which they butted. They were also machined to form a double U joint to facilitate good exographs, a gap of ⅛ inch being left at all welded joints to allow for good penetration at the center. The flanges naturally had to be perfectly round, so that they would machine truly to afford this double U section. At least ½ inch was planed off the edges of all sheared plates, which were then planed to admit of a double U weld. After they had been drilled, the tube plates were machined truly to 3/16 inches less in diameter than the inside of the Calandria shells. To admit of the insertion of the tube plates, the shells had to be rounded up a second time after welding the longitudinal seams.

The plates were all of the best 26-30 ton boiler quality, and the welding rods used were of a type that admitted of easy flotation of the slag, complete lack of porosity, good penetration, and ductility. They were devoid of any hot, short characteristic liable to result in cracks when welding thick plate. A heavy outer and inner layer of weld metal was always deposited to ensure good annealing of the weld metal underneath. This heavy layer was afterwards chipped off when the welds were ground flush with the plates before the application of the X-rays.

Altogether, about 1200 exographs were taken of the welding on the four vessels. Where an occasional imperfection, such as a small piece of slag, had to be cut out of the weld, a stereo exograph of the intrusion was invariably taken, and in this way the distance in from either the inside or outside of the weld that had to be cut out to remove the intrusion was ascertained to within 1/16 inch. This avoided cutting holes completely through the vessel, a dangerous procedure which might result in cracks in the weld.

Owing to the high working steam pressure on the shells of these evaporators, every precaution was taken in the design by Tate and Lyle's engineers to ensure safety, while the constructional work carried out in the shops of G. A. Harvey under the supervision of Mr. H. B. Fergusson had to be of the highest order to meet the requirements of the joint inspection of the engineers of Lloyd's Register of Shipping and the Vulcan Boiler and General Insurance Company.

ASSOCIATION NOTES.

CAPTAIN PAUL EDWARD DAMPMAN, U. S. NAVY, retired, died on July 19, 1936, of angina pectoris, at the Naval Hospital, Washington, D. C. He was born in Reading, Pa., on February 16, 1884, and entered the U. S. Naval Academy and graduated with the Class of 1904. During an extremely active and varied career, he did several tours of engineering duty, and in 1919, as a Commander, he was designated for Engineering Duty Only, under provisions of the Act of Congress dated August 29, 1916. From this time until his retirement in 1928, for physical disability incurred in line of his duties, he served variously at the Engineering Experiment Station, Annapolis, Md.; as Engineer Officer of the Navy Yard, Boston, Mass.; and as Naval Inspector of Engineering Material, Machinery, and Ordnance, at Pittsburgh, Pa. He is survived by his widow, Mrs. Minnie Tinker Dampman, residing at 3640 Kanawha St., N. W., Washington, D. C., and by a daughter, Miss Marjorie Jane Dampman. At the time of his death, Captain Dampman had been a member of this Society for twenty-nine years, and had devoted the best years of his life to the advancement of Naval Engineering. The many friends who appreciated the great influence he exerted on engineering development through its recent amazing era of progress, will regret to hear of his untimely decease.

ANNUAL MEETING.

The Annual Meeting of the Society was held in Washington, D. C. on Tuesday, 6 October, 1936, with Admiral William H. Standley, U. S. Navy, President, presiding.

Nominations for Officers, 1937: The following nominations were made for officers of the Society for 1937:

For President:

Rear Admiral Alfred W. Johnson, U. S. N.

For Secretary-Treasurer:

Commander Roger W. Paine, U. S. N.
Lieut. Commander R. W. Bruner, U. S. N.

For Member of Council:

Captain S. M. Kraus, U. S. N.
Captain C. C. Ross, U. S. N.
Captain J. M. Irish, U. S. N.
Captain Ralph Whitman (CEC), U. S. N.
Commander R. M. Griffin, U. S. N.
Commander A. C. Thomas, U. S. N.
Captain H. T. Wright (CC), U. S. N.
Lieut. Commander W. C. Wade (CC), U. S. N.
Commander P. B. Eaton, U. S. C. G.
Commander Ellis Reed-Hill, U. S. C. G.
Mr. Harold S. Falk.
Mr. J. H. King.
Mr. R. B. Mildon.
Mr. J. H. Nichols.
Mr. E. H. Peabody.

Votes cast will be counted after the close of business on 26 December, 1936.

Annual Banquet: It was the unanimous vote of the meeting that a banquet be held by the Society during 1937. Date and other details will be announced later.

MEMBERSHIP.

The following have joined the Society since the publication of the last previous Journal:

NAVAL.

Bradshaw, Walter R., Lieutenant, U. S. N. R., S.S. *Makiki,* Matson Navigation Co., Pier 32, San Francisco, Calif.

Chadwick, Guy, Lieut. Commander, U. S. N.

Childs, L. W., Machinist, U. S. N.

Kossler, W. J., Lieut. Commander, U. S. C. G.

Maglathlin, Webb C., Commander, U. S. C. G.

Phannemiller, G. M., Lieutenant, U. S. C. G.

Sullivan, W. E., Lieut. Commander, U. S. N.

CIVIL.

Blood, Jeremy R., 50 Cox Ave., Yonkers, N. Y.

Mochel, Norman L., Westinghouse Electric and Manufacturing Co., Lester P. O., Philadelphia, Pa.

Smith, George Brick, Box 665, Newport News, Va.

ASSOCIATE.

Danin, Gustavo, Palma, 2d Lieut. of Engineers, Chilean Navy Destructor *Riguelme,* Valparaiso, Chile.

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